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The Federal Republic of Germany's space policy is designed to promote basic research, contribute to the development of space technology, and apply the findings in the public and private sectors. It is also aimed at enhancing the competitiveness of the West German space industry and helping countries of the Third World to solve their development problems. The examples of space research and space technology given in this book also show to what degree space research is research on behalf of the earth, and that the international cooperation that evolved has become an important factor on the road to political integration. Topics discussed include: satellites; telecommunications; spacelabs; space travel; experimentation in zero gravity; radiation; time measurement; climate; cartography; and astronomy. (CW)

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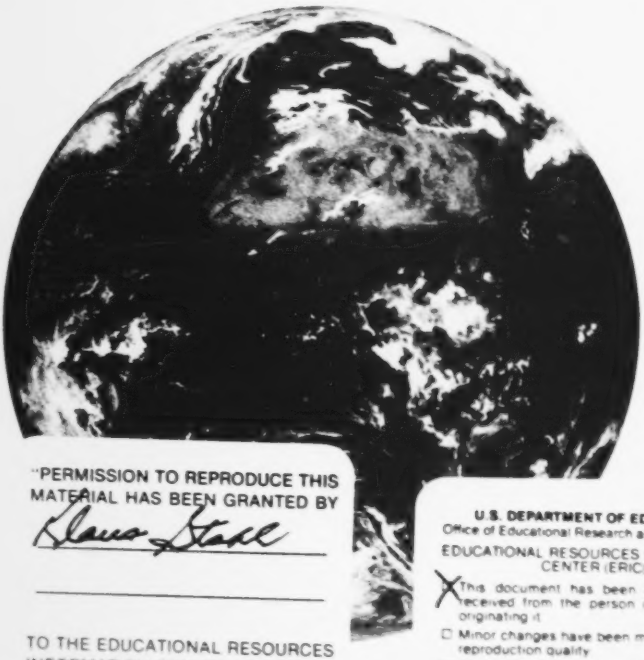
Edited by
Karl-Heinz Preuß and Rolf H. Simen



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SPACE RESEARCH in the Federal Republic of Germany

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The Federal Republic of Germany's space policy is designed to promote basic research, contribute to the development of space technology, and apply the findings in the public and private sectors. It is also aimed at enhancing the competitiveness of the West German space industry and helping countries of the Third World to solve their development problems. The examples of space research and space technology given in this book also show to which degree space research is research on behalf of the earth, and that the large measure of international cooperation involved has become an important factor on the road to political integration.

Cover: photograph of the earth taken by METEOSAT, the European weather satellite. (Photo: ESA)

Space Research in the Federal Republic of Germany

Edited by
Karl-Heinz Preuß and Rolf H. Simen

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PREFACE

Challenge and creative imagination have always been associated with the pioneering deeds performed in the field of space research and space technology. They are just as applicable today to a type of perseverance which can be simply referred to as routine. The safeguarding of this routine, the need of which was emphasised once more by the Challenger disaster on January 28, 1986, forms the point of departure in the era of space travel which is beginning now. The pioneering advances in numerous areas will now be replaced by steady research into these fields. The objective of this work is to set up permanently manned space stations before the close of the century.

The concept of consistently maintaining, repairing, and assembling structures in orbit, which is the goal of the space policy pursued by the Federal Republic of Germany, will be the basic requirement for such manned bases. They will be needed for research and more advanced ventures and serve as observation platforms and manufacturing plants.

Thus, a new dimension will be opened up in space research and space technology. There is already convincing evidence of this in the countless outstanding achievements in science and technology as well as in the many spin-offs in industry and the service sector. The new dimension has also helped create the motivation necessary for this kind of extraordinary performance.

The examples of the Federal Republic of Germany's involvement in space travel contained in this booklet are intended to describe past developments and outline the course they will follow in the future. The articles also lead to the inevitable conclusion that no one country can undertake such gigantic efforts alone, at least not in Europe. There has to be cooperation as well as purposeful independence.

Consequently, research objectives in this field are based on intensive participation in joint projects planned by the Euro-

pean Space Agency, ESA, on equally intensive cooperation beyond European borders, particularly with the USA, and on intensive basic scientific and technological research by all countries involved.

The manner in which the wheel logically comes full circle and national activity is incorporated into international collaboration is shown by this booklet which describes the development of satellite communications, Spacelab, the ARIANE carrier rocket system, COLUMBUS, the European contribution to a space station project, and planet exploration. Yet another area of activity is the observation of the earth, which provides countries of the Third World with information to help them overcome their infrastructural problems.

The support offered to space travel by the government of the Federal Republic of Germany can be summed up as follows: it is offered to science and basic research, the improvement of the service sector and infrastructures at the national and international level through application-oriented use of space transport, and, last but not least, the improvement of the industry's efficiency and competitiveness.

Since 1962, the West German government has made more than DM 11,000 million available in this field. More than 300 projects of several years' duration and costing DM 1,200 million are being carried out on a national basis at the moment. Almost 80 percent of these involve bilateral or multilateral cooperation. Public funds for space activities will be increased to an annual 1,500 million by the 1990s.

These costs represent no more than two percent of the total sum devoted to research and development in the Federal Republic of Germany at the present time; they will probably rise to three percent in the next decade. But even today, there is little doubt that the positive effects these expenditures will have on the national economy will be more than worth the effort.

If one reads between the lines in the following pages, a completely different effect of the Federal Republic of Germany's involvement in space research becomes apparent, one that

transcends all scientific, technological and economic considerations. This involvement is, without a doubt, of direct political importance for European integration, for the Federal Republic of Germany's cooperation with the USA and for its position vis-à-vis the world in general. Space research is a genuine earth-related and important task not just from the point of view of scientists and technicians. *The Editors*

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As far as the Federal Republic of Germany is concerned, satellite communication began a good twenty years ago. At that time, the first commercial long-distance telephone calls to the USA were made via satellite. Today, this form of communication has become a matter of course. It was integrated so smoothly into the world-wide telephone, data and television transmission network that hardly anyone is aware of the tremendous amount of satellite communication today or of the enormous technical developments which have taken place:

Heading for the Satellite Sky

A glance at the almost forgotten early days of satellite communication shows just how rapid this development has been at times. The first experiments with communication satellites, i.e. ECHO 1 and COURIER, began in the U.S. in 1960; the first networks were set up with TELSTAR and RELAY in 1962. As far back as 1961, the German Federal Post Office decided to participate in these experiments and build its own earth station. The site chosen was Raisting, a small place south of Lake Ammer. One of the reasons for picking this location was the fact that the "Raistinger Wanne" is unaffected by directional radio links close to the earth and is also screened by surrounding mountain ranges. Furthermore, it is far away from air routes and considered to be safe from earthquakes. It is also possible to set the antennae, operating in conjunction with satellites stationed above the equator, at a more vertical angle than in northern Germany. This helps to improve the efficiency of the antennae.

But this aspect did not become significant until later. At the time of planning, the communication link was to be established between two earth stations by means of a system of orbiting satellites in such a way that the earth stations were always

directly linked to one another via one of the satellites "visible" to both stations. Consequently, each station needed two antennae. One of the antennae was to follow the satellite handling the communications traffic at the time in question, while the other only became active when the second celestial relay station appeared on the horizon.

Before this system of orbiting satellites was put into commercial use, INTELSAT, (Consortium of International Telecommunication Satellites) was set up, a consortium which includes more than 100 member countries today. INTELSAT decided to establish a world-wide telecommunication network on the basis of synchronous (geo-stationary) satellites. These satellites travel at a height of 36,000 kilometres above the equator at the same angular speed as the earth. As a result, they seem to stand still in the sky, leaving practically no tracking problems for ground antennae. With three such satellites a telecommunications network has been set up which provides coverage for the entire surface of the earth with the exception of the polar regions. Only one antenna is needed per satellite. It can maintain round-the-clock operation with its co-station.

When INTELSAT was set up, the first giant antenna in Raisting was almost complete. At 25 metres, the diameter of its reflector or mirror is relatively small, but because the antenna was spanned by a plastic covering to protect the sensitive follow-up systems, this spherical "radome" is almost 50 metres in diameter.

"Raisting 1" commenced operations via the satellites TELSTAR and RELAY in October 1964. One month later, Siemens, the electrical engineering company, was commissioned to convert the antenna for future operations with the projected INTELSAT satellites. The first of these new satellites, the famous "Early Bird", was launched on April 6, 1965. The INTELSAT network officially went into operation on June 28. INTELSAT I has a capacity of 240 bi-directional voice circuits or one television channel. However, only two stations could be inter-linked at any one time via the satellite.

This is why the European stations of Goonhilly in the United Kingdom, Pleumeur-Bodou in France, and Raisting took over operations together with the American co-station.

The satellites of the INTELSAT II generation, sent into orbit in 1967, did not have a larger channel capacity. Nevertheless, they provided "multiple access", i.e. simultaneous usage by more than two earth stations. Furthermore, they were capable of establishing links between the northern and southern hemispheres. Two satellites were stationed over the Pacific, one joined Early Bird over the Atlantic. The arrival of INTELSAT III in 1968 offered a capacity of 1,500 voice channels per satellite. INTELSAT IV (1971) provided 4,000, and INTELSAT IV-A (1975) 6,000 channels.

This capacity was doubled by the INTELSAT V series of satellites, launched in 1980. One of the reasons for this stems from the fact that the previously used frequency band of 6/4 gigacycles per second (Gc/s) was supplemented by the frequency band of 14/11 Gc/s. Signals are transmitted via the one frequency to the satellite and beamed back on the other. Today, more than 300 earth stations are in contact with a total of 14 satellites located over the Atlantic, the Indian Ocean, and the Pacific. More than 153,000 voice circuits transmit not only telephone calls, but also TV programmes, data, and telecopies, in fact, anything which can be "digitalised", i.e. computerised.

Raisting was further expanded in line with these developments. First, Raisting 1 had to undergo several modifications to adapt to the changed radio conditions accompanying the advent of every new satellite. Raisting 2 started operating in 1969. The huge antenna bowl, from which the waves, reflected and bunched, are projected into an in-focus collecting reflector, is 28.5 metres in diameter. The idea of using a radome was dropped for technical and financial reasons: the air-condi-

One of the giant antennae of the German Federal Post Office's earth station for telecommunications via satellite in Raisting, Upper Bavaria. (Photo: Bertram-Luftbild, München-Riem, Bildarchiv der DBP)

tioning required for Raisting 1 alone costs a fortune. Raisting 3 came into service in 1972, followed by Raisting 4 and 5 in 1981 which, with a diameter of 32 metres, are even larger.

With the erection of the fifth antenna unit, expansion work in Raisting came to an end. Two antennae are lined up with the two satellites located over the Indian Ocean, three with the three Atlantic satellites. Today the German Federal Post Office has a total of 2,000 voice channels at its disposal, compared with only 38 in the early 1960s. A new "antennae array" has been set up in Usingen north of Frankfurt to permit the further expansion of satellite communications, specifically for the burgeoning European EUTELSAT traffic. Two giant antennae for the 14/11 Gc/s frequency band are ready. They are to be followed by further aerials in the 18/17 Gc/s band for the feeder service for TV satellites and in the 30/20 Gc/s band for future German telecommunication satellites.

Dietrich Zimmermann

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Technically, European and, in particular, German telecommunication-satellite engineers have long since cut the umbilical cord which used to connect them with their American models. Under the coordinating guidance of the German Federal Post Office, they are now preparing to commercialize progress by setting up efficient systems which will soon be available to all telecommunication services, including TV and telephone services and data and picture transmission:

New Telecommunication Services for the Public

The Babylonian confusion of terms and acronyms used today hardly makes it easy for the general public to understand current developments. The layperson does not know whether ESA, ECS, EUTELSAT, INTELSAT, Eurosatellite, ESOC, TV-Sat, TDF-1, 3SAT or DFS are industrial consortia, users organisations, satellites, or even ground stations.

Venturing into this bewildering game is probably best begun by a brief review of past developments. In the early days, the use of satellites seemed only worthy of discussion when it was a matter of bridging great distances, due to the high costs involved in such projects. The main reason for the German Federal Post Office to join the INTELSAT Consortium, for instance, was to secure additional channels for the rapidly growing telephone traffic across the North Atlantic. A glance at the "channel prices" shows quite clearly that this decision has paid off: rates have now dropped to one-twentieth of their original level.

At the national level everything remained relatively quiet. The two Symphonie satellites, a joint Franco-German project launched in the mid-1970s, were dispatched more for purposes of prestige rather than for intensive use as experimental carriers. The same applies to the launching of the OTS (Orbital Test Satellite) which was also undertaken in an almost

leisurely manner. Even so, this first communication satellite built by ESA (European Space Agency) and launched in 1978 played an important role as the predecessor of the European Communication Satellites (ECS).

Right from the beginning, the ECS, based on the experience obtained from the OTS, were designed using the unit construction principle, which means that their propulsion units, telemetry, communication payloads, and antenna platforms were systematically separated from one another. EUTELSAT commenced operations with ECS 1, launched in 1983, and ECS 2, which has been in orbit over Gaboon since mid-1984. This organisation, founded in 1978, has 20 European postal administration and communication organisations as members, including the 28 member countries represented in the European Broadcasting Union (EBU).

Every ECS, equipped with nine 20-watt channels, can handle 12,000 telephone conversations and two colour TV programmes simultaneously. The ECS, which are controlled by ESOC (European Space Operation Centre) in Darmstadt, are mainly intended to provide telephone communication with European fringe countries and to transmit TV programmes. In 1985, some 70 cable networks were "served" via satellite by 3SAT, the ZDF (Channel 2) programme, and the SAT-1 programme, produced by a private organisation. EUTELSAT has already commissioned ESA to produce the next generation of communication satellites. It is hoped that these new satellites, which are called "Olympus" and will weigh more than 1.5 tons (ECS 1.1 t) when in orbit, will prove to be competitive internationally.

Meanwhile, post office authorities have also become active at national level. As early as 1979, when the construction of the first ECS was still in progress, France decided to set up its own satellite system to improve telecommunications within France as well as between France and its overseas territories in the Caribbean and the Indian Ocean. A start was made with Telecom 1, which was launched in late 1983. It offers voice and TV channels as well as channels for business purposes,

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the transmission of written documents, and video-audio teleconferencing. The wisdom of this decision is shown by the fact that both the German Federal Post Office and EUTELSAT have signed contracts allowing them to use parts of the existing capacities.

An agreement signed by the German and French governments in 1980 laid the foundation for a further satellite system. The agreement includes the development, production, launching, positioning and testing of a German and a French direct broadcasting satellite (TV-Sat and TDF 1). Each of these two satellites' three channels will have the enormous output of 230 watts. It will thus be possible to transmit three TV programmes, or two TV programmes and 16 digital radio programmes. The satellites' high wattage will permit individual reception with a parabolic reflector aerial some 90 centimetres in diameter.

The launching of this German "direct broadcasting satellite" is not expected until the Spring of 1987 at the earliest. It has been funded by the Federal Post Office and the Federal Ministry of Research and Technology and built by the Eurosatellite consortium of firms. It is of an experimental nature and will only transmit "modified" programmes of the public broadcasting stations. It is still an unresolved problem whether this system can be commercialised, i.e. whether a business organisation will be found capable of raising enough capital to cover the enormous costs (DM 280 million for initial development, DM 90 million for launching costs, with at least one satellite in reserve) without charging the system's consumers too much money. Whatever the case may be, France has decided on the construction of the TDF 2 follow-up system. Contracts from abroad are expected.

The Federal Post Office has meanwhile kicked off a competition of sorts in its own backyard. In late 1983, a German industrial consortium, headed by the Siemens company, was contracted to design the DFS KOPERNIKUS (Deutsches Fernmeldesatelliten-System – German Telecommunication Satellite System). It will offer channels for all telecommunica-

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tion services, ranging from rapid data transmission and video conferencing to telephone services and TV programmes. DM 815 million have been appropriated for the construction of three satellites, namely one transmitter and one reserve satellite in orbit, and a third one on the ground. Thirty-two integrated ground stations are to be built into the existing Federal Post Office networks to handle telecommunication traffic. The TV programmes will be fed into the cable networks. To receive the signals transmitted at an output of only 20 watts, aerials three to four metres in diameter and costing at least DM 100,000 will be required.

When the first KOPERNIKUS takes off aboard the European rocket ARIANE in 1987, it will, for the first time, have a channel in the 30/20 Gc/s (gigacycles per second) frequency range on board. This means that it will be able to receive signals at 30 Gc/s and transmit them at 20 Gc/s. 14/11 Gc/s has been usual up to now. Two 11-metre-high antennae are currently being erected in Usingen and Berlin for tests which are to clarify whether such high frequencies will not become too attenuated in the atmosphere. If the transmission proves to be a success, it will mean a great step forward because 10,000 type-written pages per second can be transmitted via a "broad-band channel" of this kind. The danger that there would be conflicts concerning the allocation of these limited frequency ranges would thus have been averted for the time being. *Dietrich Zimmermann*

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Even before ARIANE made its successful maiden flight in late 1979, the planners' blue prints mentioned a concept, ARIANE 5, scheduled to be implemented in the 1990s. Naturally, these plans were dismissed by many critics of the European carrier-rocket programme as wishful thinking. Today, there is convincing proof that these critics were wrong:

ARIANE Is a Force to Be Reckoned With

Despite three abortive launches, ARIANE has turned out to be a reliable and successful system. Accordingly, the ARIANE 5 project has already been formally approved. With France as central coordinator, and at a cost of some DM 7,500 million, a newly-designed rocket will be built in the next eight to ten years which will be capable of carrying approximately 15 tons in a near-earth orbit.

There are several reasons for starting this construction programme which was approved by the governments of the Federal Republic of Germany and its European partner countries in early 1985. It is essential for the Europeans to decrease considerably the launching costs for satellites if they want to compete seriously with the Space Shuttle in the long run. This is also the goal of current developments such as ARIANE 4, scheduled to be ready for launch in 1986. Furthermore, the Europeans want to be able to transport heavier satellites than in the past. They are also anxious not to fall behind technologically. And finally, despite their plans to participate in a future US space station, the Europeans are determined to carry out their own manned space flights and to set up their own space station eventually. However, if this goal is to be achieved, an efficient and highly reliable carrier system is needed, and ARIANE 5 will be that system.

There is hardly anyone today who doubts that its construction will be successful. Unlike ten years ago when, at the

outset of the ARIANE development programme, European space flight was burdened by a history of failures, European rocket designers today can point to an encouraging balance sheet of achievements. Although the fifteenth mission (V 15) was a failure, apparently because of defects in the fuel supply in the third stage, twelve out of fifteen launchings were successful; even the heavy INTELSAT satellites were taken into orbit. Thus, the Europeans have won a market share of more than 40 percent; originally, they had hoped for only 30 percent.

Figures clearly illustrate the fundamental problems surrounding carrier rockets. When the three-stage, almost 48-metre-tall ARIANE 1 was ready for liftoff on the launching pad at the European Space Centre in Kourou, French Guiana, it weighed 212 tons. The fuel alone weighed 187 tons. The remainder, including the six power units, the supporting structure, the tanks forming the "rump", the telemetry, and the control systems, weighed no more than 25 tons, which is less than one-seventh of the weight of the fuel. It is also important to note that the tanks of the third stage contain liquid hydrogen and liquid oxygen at temperatures of −183 and −253° Celsius. In other words, a carrier rocket is synonymous with extremely light design. At the same time, however, extreme precision is called for, such as when pumping fuel into the power units – and the fuel is burnt up at a rate of some 250 kilogrammes per second.

The records of the ninth ARIANE mission, the V 9, show just how exactly an ARIANE flight takes place nowadays. The V-9 mission of May 23, 1984 served to take an American commercial communications satellite, SPACENET 1, into a geostationary transfer orbit. The fuel burn-up in the first stage, which was projected to take a little less than 2.5 minutes, was exceeded by 0.3 seconds. The fuel burn-up in the second stage, planned to take somewhat more than two minutes, fell short by 0.3 seconds, and that of the third stage (9.5 minutes) by 5.9 seconds. The separation of the first from the second stage took place at an altitude of 67.7 instead of

the calculated 68 kilometres. The point nearest to earth for the proposed transfer orbit, which is where the satellite is released, was at 200.65 instead of the at 200 kilometres, and the point farthest from the earth was reached at 35,991 instead of at 35,982 kilometres.

Even during the preparations for the serial production of ARIANE 1 (the second stage and the thrust chamber are manufactured by Messerschmitt-Bölkow-Blohm MBB/ERNO in Bremen and Ottobrunn near Munich, while the production of the other stages and the complete integration of the rocket are undertaken in France), efforts were made to increase thrust. Raising the combustion chamber pressure of the propulsion units in the first, second and third stages increased the thrust by nine percent; the twin-tank of the third stage was lengthened by 130 centimetres, permitting it to take on two additional tons of fuel. Thus ARIANE 2 was created and then further developed into ARIANE 3 by the addition of two boosters. The eight-metre-long solid-fuel rockets mounted on the outside of the first stage increase the launching thrust and are cast off when they are burnt out. The first ARIANE 3 was launched in August 1984. At a total of 2.3 tons, it can carry 600 kilogrammes more into a geostationary transfer orbit than ARIANE 1 which is rarely used any more.

ARIANE 4 is currently being prepared. It will feature an enlarged first stage and new boosters operating on liquid fuel. Each of the boosters, which will be 16 metres long and 2.2 metres in diameter, will generate a thrust of 70 tons. At an altitude of 58 metres and a weight of 470 tons, ARIANE 4 will have double the amount of liftoff mass its predecessors had. It will carry a payload of 2.3 tons into an elliptical transfer orbit. Since it is possible to vary the boosters in number and type, the rocket can easily be adapted to the requirements of different missions. This increased efficiency, however, has exhausted the possibilities offered by the basic design of ARIANE: an increase in the length of the slim middle section (2.6 metres in diameter) of the rocket, for instance, would result in problems of control because it would cause flexural vibrations.

For this reason, an entirely new, two-stage concept has been developed for ARIANE 5. Hydrogen and oxygen will be used as fuels in the first stage. They will generate a maximum thrust of 110 tons in one single but powerful propulsion unit which is currently being developed by MBB/ERNO and by SEP in Vernon, France. There will also be two large boosters, each charged with 170 tons of solid fuel. In view of the varied missions, two systems are planned for the second stage: a conventional stage and one operating on hydrogen/oxygen. It is hoped that this carrier, which will have the same cargo capacity as Space Shuttle and which can transport eight tons into a geostationary transfer orbit or fifteen tons into a lower orbit, will lower launching costs for satellites by one-third. In addition there are plans to use this rocket for a manned spacecraft sometime in the future. France has already decided to participate in the construction of this vehicle called HERMES. The French, moreover, will be responsible for centrally coordinating the ARIANE 5 project and bear about 53 percent of the cost. The German share will be about 22 percent. The present percentage ratio is approximately 60:19.

Dietrich Zimmermann

The launching of ARIANE, the European rocket carrier, at the space station in Kourou, French Guiana, South America. (Photo: ESA)

Once the use of the Space Shuttle had become almost as much a matter of routine as the construction of earth satellites, the great day also came for Spacelab. On November 28, 1983, Spacelab, built in the Federal Republic of Germany, embarked on its first mission on board a Space Shuttle. D-1, the latest venture, launched on October 30, 1985, will undoubtedly not be the last:

Spacelab Stands the Test

The Orbital Technology Laboratory "Spacelab", especially conceived for the shuttle programme, was designed and built under the industrial leadership of the space systems group, Messerschmitt-Bölkow-Blohm MBB/ERNO in Bremen, which was under contract to the European Space Agency (ESA). The main contract was awarded to MBB/ERNO in the summer of 1974. More than four dozen firms from Belgium, Denmark, France, Italy, the Netherlands, Switzerland, Spain, the United Kingdom, the USA, and, of course, the Federal Republic of Germany were involved. There was even a contribution by Austria, an associate member of ESA. About 55 percent of the development costs amounting to some DM 2,000 million came from the budget of the Bundesministerium für Forschung und Technologie (Federal Ministery of Research and Technology). These funds had to be made available prior to Spacelab's first mission in the fall of 1983.

Spacelab was designed as a multi-purpose platform where experiments can be carried out in a manner as similar as possible to that of a laboratory on earth. It consists of two different component parts which can be installed firmly and precisely into the Space Shuttle's cargo bay, and which can be combined in different ways, depending on the requirements of the mission. The first unit, known as the "module", is a hermetically sealed cylindrical container with a diameter of about four metres. It is connected by a tunnel to the orbiter's middeck. Payload experiments under terrestrial atmospheric conditions can be conducted here; the instruments are placed

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in standardised racks and on laboratory work tables flanking the central gangway.

The second basic unit is called the "Pallett", a U-shaped platform equipped with instruments that can be operated from the orbiter or the ground. The Spacelab mission in the late Fall of 1983, for instance, was a configuration of a basic and an experimental segment (Long Module) and a Pallet. For the second Spacelab mission in early 1985 (designation SL3), NASA used the Long Module and supplemented the flight configuration with a carrier structure. An unmanned Pallet version only, plus service module IGLU, was used for the first time during the third mission in July 1985. All integrated instruments and experiments, including the telescope using the highly accurate German IPS pointing system (see page 108), were controlled by the orbiter crew. The first D-1 Spacelab mission under German mission management took place when the fourth mission was launched in the Fall of 1985, with the Long Module and a carrier structure based on the Shuttle Pallet Satellite SPAS. The life science investigations during this first mission under the direction of the control centre in Oberpfaffenhofen were mainly focused on vestibular reactions. In several experiments, a team of European and American medical experts, headed by Prof. Rudolf von Baumgarten, tried to track down disturbances in the human balancing mechanism.

The early Spacelab missions were devoted almost entirely to basic research and material sciences. This kind of research will undoubtedly continue to be of primary importance. It goes without saying that a lot of the experiments will investigate the effects of weightlessness. Even though gravitation is caught in the balance between the earth's attractive powers and centrifugal force on these missions, it is not completely eliminated. Be that as it may, it is nevertheless reduced to one-thousandth or even one ten-thousandth of its value on earth. Broadly speaking, the programme covers six main scientific and technical areas: earth observation, astronomy, biology and life sciences, material research, and space technology. The long-term objec-

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tive, of course, is the construction of larger space stations, both for further research purposes as well as for the production of materials which, because of gravitational force, cannot be manufactured on earth. The COLUMBUS project has also confirmed this goal by now (see p. 35).

Since the necessary equipment, materials and instruments for the construction and operation of such space stations have to endure stress conditions which cannot be simulated on earth, several Spacelab experiments dealt with developments of this nature right from the outset. Among other things, space stations must be able to carry large telescopes and antennae as well as a gigantic mirror 100 metres in diameter. These will be used for both celestial and terrestrial observations.

The Federal Republic of Germany has made a considerable contribution to the realisation of these projects, including the development of important supplementary equipment by institutes and firms. One example is MAUS (autonomous materials science experiments in weightlessness). MAUS is a container system in which minor experiments can be conducted autonomously, and which can be set up almost anywhere in the Pallet area as well as on SPAS, the Shuttle Pallet Satellite (see page 30) developed in Germany. MAUS had its first success during the fifth Space Shuttle mission, and SPAS during the seventh in June 1983.

The Space Shuttle "Challenger", carrying Spacelab's D-1 mission was launched from Cape Canaveral on October 30, 1985. The flight was scheduled to last seven days, orbiting at an altitude of 324 kilometres. The designation D-1, incidentally, points to the fact that the coordination and mission

Spacelab, built in the Federal Republic of Germany, set off on its D-1 mission under German management on board an American spacecraft at Kennedy Space Center, Florida, on October 30, 1985. The picture shows the liftoff of a spacecraft on a previous occasion. (Photo: NASA)

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control of the scientific payload was in German hands. The 76 experiments carried out by a total of 64 experimenters came principally from German universities and institutes; other European and American experts were involved via ESA and NASA. Mission control was the responsibility of the Cologne-based project group Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt, DFVLR (German Aerospace Research Establishment). Its tasks included selecting and training scientific astronauts, assembling and coordinating the experiments, defining framework conditions and, supported by industry, assisting in experiment development as well as monitoring the experiments and the scientific support of the astronauts inflight from the research centre in Oberpfaffenhofen.

The common denominator of most of the experiments again was what is called "micro-gravitation", i.e. near-weightlessness. Research activity was concentrated on two focal points involving about 50 experiments with materials and 25 with humans.

Apart from the American commander and his co-pilot, the eight-man crew included three American mission specialists and the three scientific astronauts. The two Germans, Reinhard Furrer and Ernst Messerschmid, and Wubbo Ockels from the Netherlands, made up the basic Spacelab crew. It was their job to operate and monitor the experiments. Ulf Merbold took part in the first Spacelab flight in the autumn of 1983 and helped monitor this mission from the Oberpfaffenhofen control centre. The American mission specialists were responsible for the smooth running of Spacelab's operational systems and for specific experiments. Altogether, five mission specialists and scientific astronauts could operate in two shifts round the clock.

The D-1 flight cost the Federal Republic of Germany DM 402 million. DM 160 million was paid to NASA for launch and mission of the Shuttle. The German experiments, the preparations for the mission, and the installation of essential ground facilities accounted for a further DM 240

million. The costs of foreign experiments were paid for on an individual basis by the institutions and authorities concerned. One thing is now certain: the mission was highly profitable from a scientific point of view. The financing of D-2, the second German Spacelab mission, scheduled for the very late 1980s, appears to be practically guaranteed.

Dietrich Zimmermann

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After Columbia's initial flights had proven that the Space Shuttle was ready for use, the interest of scientists and engineers was concentrated on exploring the possibilities offered by this new type of space transportation system. The Europeans, like others, intend to make full use of this newly created access to the near-earth orbit. One outstanding example of the many research efforts in this area is the space platform SPAS-01, designed by the Messerschmitt-Bölkow-Blohm (MBB) aerospace company. SPAS-01 was the first satellite to be brought back to earth. It's further development EURECA deserves special attention as well:

Round-Trip Satellites

"SPAS" is the abbreviation for "Shuttle Pallet Satellite", a space vehicle which was especially designed for the Shuttle. The term "pallet" indicates that the basic structure, similar to conventional transport systems using pallets, only has a carrying function. It is merely an elongated latticed frame of super-light but extremely robust design.

The basic element of SPAS is a cube-like, carbon fibre-titanium lattice with an edge length of 70 centimetres. When six such elements are joined together, a bridge-like construction 4.2 metres in length is created which completely spans the Shuttle's cargo bay. If this carrier construction is fitted with a foot, resting on the floor of the hold, the satellite's basic form is complete. This lattice-like construction has been designed to transport both payloads and the power, control and communication systems.

A total of eight experiments had been designed to be carried out aboard SPAS-01 when, as a prototype, it was sent into orbit on the second Challenger mission in June 1983. Six of the experiments were financed by the Bundesministerium für Forschung und Technologie (Federal Ministry of Research and Technology) and two by the European Space Agency (ESA). Three camera systems came from NASA. The set-ups were to conduct materials science experiments under micro-gravity

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conditions, and neutral mass spectrometer experiments. The cameras were optoelectronic scanners for remote sensing and cameras for filming the Shuttle itself, as well as earth sensors and heat pipes, which are so extremely important for space technology.

These experiments were conducted on the outer structure. Fully equipped, SPAS-01 took up the space of a 1.5-metre-thick disc in Space Shuttle's 10-metre-long cargo bay. It weighed about 1.5 tons, 0.85 of which was accounted for by the experimental apparatus, which is a highly favourable ratio. Thus SPAS-01 made optimal use of Space Shuttle's available space; 1.3 tons per running metre is permitted.

Experiments were carried out with SPAS-01 for some 39 hours. The platform spent about 16 hours altogether in free flight outside the Space Shuttle at a distance of up to 300 metres. It was released by a manipulator five times and then retrieved without the slightest difficulty. The highlight of this mission was undoubtedly the pictures taken of Challenger by a colour TV camera mounted on SPAS. They were brilliant in colour and of high-definition, and were, in fact, the very first "space photos" of the Shuttle taken from a satellite. Since a series of shuttle systems were being tested during this phase, and since the operational behaviour of the space vehicle in terms of releasing and recovering satellites was also being examined, NASA had agreed to assume part of the launching costs. Incidentally, the development of SPAS alone cost some DM 25 million.

The platform, which also proved its worth as an experiment carrier in the cargo bay, was used a second time in February 1984, this time with eight scheduled experiments, including two completely autonomous scientific experiments with materials. Once again SPAS functioned without a hitch. The fact that the scheduled training programme for subsequent satellite repairs did not take place is due solely to the jamming of a joint in the manipulator arm, forcing SPAS to stay in the cargo compartment. As a result, only a few docking and work manoeuvres could be carried out.

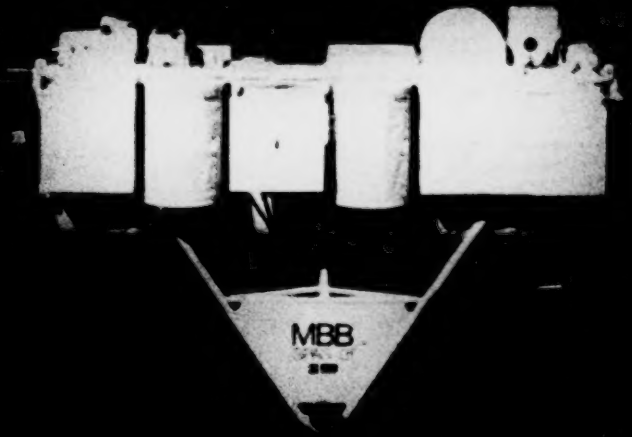
The European Retrievable Carrier (EURECA), designed by MBB/ERNO under a contract awarded by ESA, is the direct successor to SPAS. It is a type of unmanned mini-space platform to be released for the first time at an altitude of 300 kilometres by a Space Shuttle in late 1987. The self-operating platform, piloted and controlled from the ground, will then climb into orbit at a height of 500 kilometres, return to the shuttle orbit on completion of the experiments and a waiting period of about three months, and then finally be taken on board the Space Shuttle again.

The structure of EURECA, which is based on the SPAS lattice design, is four metres long and 2.45 metres wide. The prototype will weigh 4.2 tons, one ton being accounted for by the payload. The platform has its own communication and energy supply system, including two solar-cell wings. Its thermal economy, consisting of active and passive components, resembles that of conventional satellites. High demands are placed on the attitude control system: plans call for using terrestrial and astral sensors for exact positioning.

EURECA will not only be used for long-term experiments, but also for the development of new rendezvous and docking techniques, which are new to the Europeans. These techniques are essential for regularly replenishing and servicing the platform or for exchanging the payloads. In order to prescribe the coupling mechanisms, ESA has commissioned a study. The German firms of MBB and Dornier, in collaboration with Aeritalia, British Aerospace and Matra (France), have already outlined the first definitions for a demonstration mission.

In these calculations, the following model scenario was used: an unmanned platform will be released into space by a shuttle and then guided from the ground to an orbit at a height of 500 kilometres in the proximity of the station to be replenished. The target, i.e. the station, will have a passive

The re-usable SPAS-01 satellite, built in the Federal Republic of Germany by MBB/ERNO, during a free-flight manoeuvre in space. (Photo: NASA)


MBB

docking adapter, while the tracker-satellite will be equipped with an active coupling system. After carefully approaching and docking, the tracker-satellite can replenish the station's propulsion system, check and readjust the sensors and propulsion components, overhaul the mechanical systems, and check the batteries in a matter of days. It will then be uncoupled and return to the shuttle's orbit, subsequently be retrieved, and eventually brought back to earth. According to the study, SPAS would be particularly suitable as the target and EURECA as the tracker for the development of this technique. Will they be the pacemakers on the road to a European space station?

Dietrich Zimmermann

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Following a government decision in 1985, the Federal Republic of Germany will take part in the two major projects to be carried out by the European Space Agency (ESA). This implies involvement in the further development of ARIANE, the European launcher system, and in systems relating to the American manned space station. The European contribution to the permanent space station, COLUMBUS, will be developed under German system management. It will cost about DM 7,400 million and be ready for use by about 1994:

A Signpost for the Future in Space

In mid-1984, U.S. President Ronald Reagan commissioned NASA to construct a permanently manned space station by the year 1992, the 500th anniversary of the discovery of America. The final concept of this station, which is to orbit the earth at a height of 300 to 400 kilometres in the proximity of the equator, has still not been settled. In all probability, the core will consist of a central multi-docking installation: several modules, towering into the different space axes, will be docked there. In addition, there will be a service unit complete with manipulators for handling the free-floating platforms and a "power station", which will have solar cells covering an area of 2,000 square metres and an output of 72 kilowatts.

The living and working modules, of which there will probably be four at first, will be up to ten metres long and a generous four metres in diameter. They will provide 200 square metres of air-conditioned interior space. Thus, they will be adequate for a six- to eight-person team to live and work in for a few months before being replaced by a new team via a shuttle. The weight of this basic construction stage, which can be enlarged by docking further modules and segments, will be about 35 tons. The parts will be taken into orbit by several shuttle flights and then assembled by the astronauts themselves.

COLUMBUS, the European contribution to this station, is

based on a German-Italian concept which was designed explicitly to satisfy the needs of future users. It consists of four different elements which could become the basis of a subsequent autonomous European space station in the long run, provided one regards the whole project as a series of stages. The most important element is the PM (Pressurised Module), a cylindrical element somewhat similar to the Spacelab modules. It will be integrated in the space station's central unit and is, in principle, comparable with the American and Japanese modules. "Pressurised" means that the conditions prevailing in the module resemble those on earth, i.e. there is overpressure vis-à-vis surrounding space, permitting the astronauts to move around without space suits.

The PM is a micro-gravity laboratory and will, in the first instance, be provided with all necessities for living and working, including data switching systems, sleeping, living and sanitary units.

The second COLUMBUS element is a flight configuration comprising two elements, e.g. an unmanned resource module and a two-segment pressurised module, called Man-Tended Free-Flyer (MTFF). The design and development approach for the resource module is based on the principle of achieving maximum commonality with the utilities and propulsion modules to be developed for another element, the polar platform. The design goal for the MTFF is to provide micro-gravity sensitive payloads with relatively long periods of very low micro-gravity levels while retaining the flexibility for periods of mantending for payload operation, servicing and exchange.

A model of COLUMBUS, the European contribution to the manned US space station. The COLUMBUS module, which is being constructed under German system management, will be coupled to the space station base, but will also be capable of going on independent flights for brief operation periods.

(Photo: ESA)

COLUMBUS
MBA

The third element is an unmanned polar platform (PF) with the capability of in-orbit servicing and payload exchange. The platform reference configuration is sized to provide up to 5 kW power to the payload. Its nominal operational altitude is approximately 850 km, in a sun-synchronous orbit. The primary function is to accomodate earth observation payloads.

In addition, a co-orbiting platform will be studied as an option for future tasks. It is based on an enhanced EURECA now under development and ready for launch in early '89. EURECA is a further development of MBB-ERNO's Shuttle Pallet Satellite, SPAS, which has already been operated successfully aboard a shuttle twice. MBB-ERNO, a contractor of ESA, is responsible as system prime for the COLUMBUS preparation phase which is expected to be concluded in the Spring of 1987 and to be followed by the development phase.

COLUMBUS will by far be the Federal Republic of Germany's most expensive space transportation project to date. Of the total costs amounting to DM 7,400 million, the Federal Republic is to assume at least 37.5 percent, followed by Italy (25), France (20), and the United Kingdom (15).

Dietrich Zimmermann

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At the point where conventional propulsion units would have long been exhausted, AGORA, a research probe, will still continue to travel actively through space. During its mission, which will last more than six years, AGORA will systematically circle around and explore the small planets Vesta, Thetis and Hersilia using six power units developed at the University of Gießen.

Journey to the Planetoids on an Ion Beam

AGORA, however, is still only one of many projects planned by ESA (European Space Agency). Its launching has been no more than theoretically scheduled for 1993. Even so, one cannot reach out for this possible reality less hopefully than physicist Horst Löb did 25 years ago when he set about turning this seemingly fantastic idea into fact. Today, Professor Löb is head of the Plasma Physics Department, 1st Physical Institute, Gießen University. From his pioneer dream have emanated a whole series of ion-propulsion units which easily hold their own in the face of world-wide competition.

The Gießen propulsion unit RIT 10 is currently being prepared for a test flight on board EURECA, which is the space platform EURECA, which is scheduled to take off in late 1987. It is being developed by MBB/ERNO, a space systems group. RIT 10 will weigh around 3.5 tons and be released as a carrier element for various experiments by Space Shuttle at an altitude of 300 kilometres. Then, under its own power, it is to climb into orbit at a height of 500 kilometres, stay there for about six months, and then return to the lower orbit where it will be retrieved by a shuttle. Whereas, in this case, RIT 10 could take responsibility for the steering of the platform, the larger RIT 35 is regarded as a propulsion system and is to be installed six-fold in AGORA. On board EURECA, RIT 10 is to be operated for a minimum of 2,000 hours. With respect to the AGORA project, on the other hand, each

of the propulsion units is expected to provide operational periods of 9,200 hours on average.

Everything depends on these long "operating times" provided by the electric propulsion units, since they are by no means powerful in the accepted sense. As Dr Klaus Groh, head of the Working Group for Propulsion Unit Development, explained, RIT 10 can only move about one gramme, RIT 35 no more than 20 grammes. If, however, this marginal thrust is used long enough in space – for hours, days, weeks or even months – the travel gain is enormous. It is also feasible since the size of the tanks required for such ion-propulsion systems is not excessive. For a mission lasting more than six years, for instance, AGORA will need only one ton of mercury to fuel the space vehicle's electric propulsion units. This can almost be described as minute in view of the magnitude of the undertaking. It makes a good case for the use of this type of propulsion system because its range is unsurpassed.

The physical background of this weight-saving stems from the fact that the space vehicle's momentum, provided by the power system, is derived from the mass of the matter expelled in the propulsion jet, multiplied by the matter's speed. In other words, if the possible speed is very high, the mass can be correspondingly small to achieve the given pulse amplitude. In the case of ion-propulsion units, this jet velocity is ten times greater than the best (chemical) rockets. At 40 to 50 kilometres per second it achieves breathtaking values. The "fuel" in such cases is, of course, electric energy from batteries or, as in the case of AGORA, from two 30-metre-long and 3.3-metre-wide solar-cell wings with a total output of 25 kilowatts. The contents of the tanks, be it mercury (as in the case of the RIT 35 power units), or the heavy inert gas xenon (used for the RIT 10), are, so to speak "energyless".

Mercury and xenon are used purely for the production of a propellent reaction impulse in such a way that they can be accelerated atom by atom to incredible speeds, which are only possible in electrically driven propulsion systems. However, this goal can physically be achieved only if the atoms are

provided with electrical sails blown by a hurricane, which also is electrical. Such sails are created if the individual atoms are electrically charged or ionised; only when they are charged can the accelerating electrical forces act on them.

Consequently, the "combustion chamber" of these ion-propulsion units is a so-called "ioniser"; a "neutraliser", ejecting negative charge carriers (electrons), must also be included in the propulsion system. Otherwise, the constant impact of exclusively positive ions would cause vehicles powered in this manner to charge themselves negatively. This, in turn, would eventually render the jet propulsion ineffective as a result of self-generating electrostatic forces. It was this aspect, in particular, which formerly prompted the experts to expect problems; but at the present state of the trials these problems have not materialised. On the contrary: the use of such ion propulsion systems is being considered to overcome systematically the electrical charging of spacecrafts.

Incidentally, the number following each of the RIT designations for the propulsion units denotes the size of the ionisers. With a diameter of 35 centimetres, the RIT 35 is currently the largest of the Gießen models, together with the RIT 15 and the RIT 10. The smallest version is no more than four centimetres in diameter. With the AGORA project in mind, work has been in progress under a contract awarded by ESA on the RIT 35 since 1984. The eventual objective is to prepare the propulsion unit for industrial production.

The Gießen propulsion units are not only of importance as far as space is concerned, but they might also help to solve problems in the physical-technical treatment of work-material surfaces. They can also be used in the development of controlled nuclear fusion and of reactors designed to produce energy from artificial solar heat. This heat is ignited in plasma consisting of heavy hydrogen (deuterium) and super heavy hydrogen (tritium) which is so effectively retained in the heart of the reactor by powerful magnetic fields that it cannot come into contact with the reactor's walls. The biggest headache continues to be the temperature increase to the inflammation

point of 100 million degrees Celsius. The solution to this problem might be forthcoming with the Gießen propulsion units and their extremely energy-rich ion beam. Talks are already going on with Max Planck research experts in this field about using these units for this purpose.

Rolf H. Simen

2

Of all the investigations conducted by scientists in perigeal (near-earth) space, research into micro-g is probably the area least understood by the general public. Yet it almost dominated all activity on the Spacelab Mission D-1. Micro-g, which is a somewhat cryptic designation for the layperson, represents a new path to findings, materials and techniques whose multiple ramifications have not yet been assessed in their entirety:

Micro-Gravitation and Matter

It may only be the designation of these experiments, or quite possibly their complex nature, which makes it so difficult for scientists to make them comprehensible for the general public, not even taking into account frequently used terms such as "new work materials". It is worth noting that all these investigations are concerned with the inner world of matter, which is something with which only specialists are familiar. This research deals with effects which are anything but common knowledge.

The term "g" is derived from the variable "g" used by physicists to denote gravitational acceleration. In physics, "g" means that a body in free fall reaches a speed of 9.81 metres a second, one second after being released in the direction of the earth. In other words, g = 9.81 metres per second per second (m/sec^2) is the value used to describe the earth's force of gravity.

Earth satellites or space stations escape from this force of gravity in the same way as, in an imaginary experiment, a stone is thrown at such a speed that its extreme arc does not allow it to fall back to earth; instead, its fall-back curve extends around the earth. At least theoretically, the stone is in a permanent state of falling, caught in the balance of centrifugal force which carries it away from the earth and the force of

gravity. Although gravitational force continues to exercise its influence, it is reduced to nought in the face of this balancing act: force g vanishes.

Depending on orbit altitude, earth satellites and space stations in reality do brush the fringes of the earth's atmosphere or are exposed to other orbital interference. The earth is not a perfect sphere but a slightly pear-shaped geoid with regional differences of gravitation. This disturbs the balancing act between centrifugal and gravitational forces and leads to residual speeds varying from one thousandth to one ten-thousandth of the earth's acceleration. Thus, micro-gravitation, the so-called micro-g condition, does exist. Nevertheless, the unit g which frequently determines all the physical, chemical and biological processes on earth, becomes totally negligible for all practical purposes.

Metaphorically speaking, this means that a burgeoning crystal no longer has to grow in opposition to gravitation; it can reach its natural form in an ideal manner, at least theoretically. Under such conditions, various heavy metals may form alloys which do not exist on earth simply because its gravitational force would separate them even as they are forming. Since "above" and "below" become meaningless in this process, hydrostatic pressure and convection currents, such as occur on earth above a lit candle or hot stove, do not exist. Surface tensions and boundary layer effects manifest themselves in a different way and reveal innate qualities previously suppressed by gravitation. This is also important for organic chemistry and biochemistry. The chemical linkages experienced in these areas are often so weak that the absence of gravitation could, indeed, assume a role which could be exploited in application. Practical applications of this fact could be in developing particularly accurate analyses or producing monocrystals from proteins, and, last but not least, manufacturing new types of drugs.

Examples of such materials naturally include monocrystals consisting of semiconductive substances used in producing electronic or highly-integrated circuits, as well as new types of

alloys, dispersion-hardened work materials of widely varying types, or new materials such as amorphous metals of a non-crystalline structure which virtually "freeze" in the fused mass, similar to conventional glass (so-called metallic glass). Furthermore, there are the recently discovered material states of crystalloids, found, as it were, in the fringe area between crystal and glass.

One could fill pages with prospects of this nature. Here, however, we quote just one example of the many possibilities to underscore the difficulties besetting the realisation of a fascinating idea in the normal course of events. The fact that the technologists' dream of being able to cultivate crystals in the weightlessness of space is not successful in every case became first clear on June 22, 1983. On this date, during the seventh Spacelab mission on board the first free-flying re-usable SPAS-01 satellite, a physical phenomenon, which is of secondary importance on earth, made its presence felt during the important stage of an experiment designed by the Department of Physics at Gießen University.

The disturbance factor to crystal growth in space, which is being examined by Dr Dietrich Schwabe, is what is known as the "Marangoni Convection". It is a compensating current which appears, for instance, on the surface of meltings whenever they are heated at irregular intervals and results in changes of surface tension. On earth, this phenomenon occurs in conjunction with the normal convection process caused by heat. But unlike this normal convection, the Marangoni Convection does take place in the weightlessness of space. Schwabe discovered that under certain conditions, this effect leads to irregularly oscillating (!) material currents within the meltings, which eventually reveal themselves as "growth strips" inside the finished crystal.

This discovery, which was corroborated by results obtained from a Spacelab experiment undertaken by the Department of Crystallography at Freiburg University, seemingly contradicts an earlier Skylab experiment designed by researchers from the Massachusetts Institute of Technology (MIT). They produced

ideal crystals from indiumantimonide in a closed ampulla. The metalloid, silicon, so highly important in semiconductor technology, expands when it hardens. In other words, it cannot be crystallised in closed containers. Consequently, its uncovered surfaces are automatically exposed to the Marangoni effect. Thus Schwabe's statement to the effect that the production of better and more evenly structured silicon crystals will be difficult, remains valid. At the same time, it also becomes understandable why processes such as "floating zone melting", which are completely incomprehensible to the layperson at first sight, are among the focal points of the micro-g work material experiments, and why such research may well result in many a surprise and many a step forward.

Rolf H. Simen

By means of sophisticated medical research programmes, German scientists are taking steps to ensure that the dream of doing work in a state of weightlessness will not become a nightmare. Only if this problem is solved can the basic conditions for permanent human settlement in outer space be created:

Weightlessness – And What Comes Next?

Floating weightlessly is an old dream of civilised societies, a dream which implies the possibility of escaping from the banal worries of life on earth. For one human profession this dream has come true, i.e. the small band of astronauts. Yet, from what they have told us, weightlessness is anything but a dream. At the start of each mission they feel seasick, as though they were aboard a ship.

If one examines the structure and function of the human body, it soon becomes clear that several adaptation problems will have to be overcome before floating can become a sheer joy. Only during the course of his phylogenetic development did man start to walk upright. Anyone who has tried to balance a broom handle realises that a sophisticated system of equilibrium is needed to maintain an upright position without difficulty. Here, the vestibular system in the middle ear has a key function. It is the first to lose its equilibrium in space since it is no longer needed. This hardly contributes to a sense of well-being.

This organ would not get very far without the supportive aid of the muscles. About three-quarters of man's muscles assist him to move in the earth's gravitational field, as we are accustomed to doing. In space these muscles become superfluous and slowly recede. This happens very gradually, however, and can be counteracted by special training. Calcium content, the decisive substance for bone structure, also slowly decreases. A loss of ten percent was established after a period

of 80 days.

Less conspicuous features of our body are likewise governed by our gait. Over the thousands of years of human development, the circulatory system has adjusted to the situation created by the earth's force of gravity on an upright, elongated body. This gravitational pull constantly forces the body's fluid downward; the blood falls into the legs and exerts hydrostatic pressure there. A compensating mechanism consisting of pumps and valves – muscles and veins – is responsible for relocating the blood in the upper parts of the body. But how does such a mechanism react if it is no longer needed? How long does it take the human organism to adjust to this new situation?

Professor Karl Kirsch and his team from the Department of Physiology at the Freie Universität Berlin (Free University of Berlin), sought answers to these questions during the ESA (European Space Agency) Spacelab flight in the autumn of 1983. These experiments were conducted under the auspices of the Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt, DFVLR (German Aerospace Research Establishment), in Cologne and financed by the (Bundesministerium für Forschung und Technologie (Federal Ministry of Research and Technology).

The first and surprising conclusion drawn from the results is that the first measurement in space was made too late. After a period of 22 hours, the adaption process which the experts were intent on examining had already taken place: the cardiovascular mechanisms had rapidly adjusted to the new situation. This, however, does not mean that the data obtained has little value. On the contrary: it showed the experts that "the adaption processes are extremely dynamic, much faster than we had assumed theoretically", Kirsch explains.

What, then, was so special about the measurements? Manned space flight is now a quarter of a century old, and reports by a large number of astronauts have been available for study. They all stated that as soon as they experienced weightlessness, their legs became weak while their upper body and head

became extremely swollen. The pressure-compensating mechanisms easily explain this: initially the blood continues to be pumped out of the legs into the upper half of the body even though the counterforce of gravitation no longer exists. The pressure in the veins in the upper half of the body increases. They react to the situation: the vascular walls, used to conditions on earth, interpret high pressures as an excess of water. Two hormones are mainly involved in this highly complicated, finely controlled reaction. The anti-diuretic hormone from the neurohypophysis, generally known as an active hypertensive agent, plays an important part in osmotic regulation, i.e. in maintaining a specific level of dissolved substances in the body fluid. Aldosterone, originating in the adrenal cortex, controls the balance of electrolytes (dissolved salts) in the blood.

Once the organism's water control system registers this presumed excess of fluid, the anti-diuretic level drops, and the level of aldosterone rises. Increased discharge of urine simultaneously reduces the sensation of thirst and causes a decrease in water intake. The total volume of fluid decreases, which explains the loss of weight during space flights. On return to earth, this loss of weight is rapidly compensated for by increased drinking. Kirsch, a specialist in gravity physiology, draws a further conclusion from this: "A person needs an additional three to four litres of water to exist in gravitation."

The special new feature of the Spacelab expedition experiments was the fact that, for the first time, intravascular measurements were taken in space: the astronauts themselves inserted a needle into the bend of the elbow which, by means of an electronic device, measured and recorded venous blood pressure. In all four test persons the pressure in the veins was lower than it was on earth: the counteraction to the transfer of volume from the legs to the top half of the body had apparently been very quick. After measuring their venous pressure, the astronauts extracted a few drops of blood with the needle. They then carried out a haematocrit test which

established the level of water in the blood. They discovered that their blood had, indeed, thickened; the volume of blood plasma had decreased. Part of the sample was frozen so that the hormone content could subsequently be established at the Berlin laboratory. Since, however, the control mechanism was faster than previously assumed, no further deviations were registered in the anti-diuretine and aldosterone.

During the D-1 mission, Kirsch and his colleagues also conducted experiments to establish venous pressure during weightlessness. He states: "The most important lesson we have learned is that we must neither extrapolate or interpolate." This means, on the one hand, that observations made on earth do not automatically permit conclusions to be drawn concerning the organism's behaviour in space. On the other hand, isolated readings, such as those taken after 22 hours, should not serve as a basis for drawing conclusions on complex processes. If the process of adaption is to be studied more closely, measurements must be taken soon after liftoff. Ideally, continuous readings should take place throughout the whole flight by means of indwelling catheters. True, this technique involves certain hasards and some unpleasantness. But the experiments have shown one thing: biological systems are much too dynamic and complex to be described with simple theories on the basis of a few measurements.

Before the dream of working under weightless conditions and of permanent settlements in space will come true and make countless scientific studies possible, many further measuring programmes, similar to the one for venous pressure, will have to be carried out. This will help avoid the dream of weightlessness from becoming a nightmare one day.

Jürgen Neffe

One of the theories on human balance orientation, considered correct for the last 70 years, has now become the subject of doubt following the first flight by Spacelab, the German space laboratory, in the Fall of 1983. A physiologist from Mainz and his European research team have been able to disprove parts of this theory as the result of experiments carried out for the first time without the dominating influence of the earth's gravitation.

Somersaults in Space – In the Name of Science

In 1973, 21 minnows circled the earth in the first US skylab for a period of three months. These tiny fish owed their trip in the skylab to physiologist Professor Rudolf von Baumgarten. He was carrying out research in balance; the fish were expected to provide further information.

Von Baumgarten, a member of the teaching staff at Mainz University, did not really get near his real research goal, i.e. the functioning of the vestibular system, until ESA, the European Space Agency, launched the much more spacious Spacelab in the autumn of 1983. Here, for the first time, the physiologist and his team of European equilibrium researchers were given the opportunity to conduct extensive experiments with humans in a state of weightlessness. The results of their experiments with the four-man crew of the Spacelab caused a sensation and cast serious doubts on a scientific theory which has been accepted for 70 years and even awarded the Nobel Prize, namely the explanation of the so-called "caloric nystagmus".

The vestibular system is located in the inner ear. Apart from hearing, it is also responsible for maintaining an upright posture and not losing sight of a selected objective despite body movements. Protected in the depths of the lateral cranial bones, the inner ear follows onto the external auditory canal, the eardrum, and the tympanic cavity with its three middle-ear

ossicles, i.e. hammer, anvil, and stirrup. The middle-ear ossicles transmit and amplify the sound waves picked up by the eardrum. A thick-skinned membrane receives the vibrations and passes them on to the inner ear, to the so-called cochlea. Lymphatic fluid in the osseous convolutions of the cochlea thereupon starts to move, finally reaching tiny, upright sensory hairs inside the cochlea. This stimulates the auditory nerve leading to the brain.

Posture and balance are governed by similar processes. Lymphatic fluid is also contained in the inner ear, namely in three osseous semicircular canals. The particular feature about these canals is their position in relation to each other. Each of them roughly corresponds to one of the three dimensions: vertical, horizontal and frontal. Each is closed off unilaterally by a gelatinoid crest (crista). The sensory hairs of the nerve cells grow out of the base of the crista.

Side-to-side movements of the head cause the fluid in the semicircular canals to "slop" against the gelatinoid crests which immediately convey this stimulation to the brain via the vestibular nerve. Linear motoric stimuli are received by sensory hairs in two osseous recesses joined to the semicircular canals from below. There, the tiny antennae stand close together on narrow measuring patches, each of them towered by a gelatinoid membrane. Both these hoods, which together form the otoliths, are covered with calcium crystals.

When the body is in an upright position, the earth's gravitational force draws one of the two gelatinous hoods perpendicularly and the other horizontally down to the nerve hairs growing below them. This permanent stimulation of the vestibular nerves is merely a reflection of the normal gravitational attraction our planet exercises; it is not consciously noticed. Only when the head is inclined do the gelatine hoods and the related otoliths become effective. The hoods slide along the sensory hairs in the same direction as the head. The brain then deciphers the resulting stimuli by conveying the angle at which the head is bent. The brain, however, is not content just to register the head's changed position. On the

contrary, upright posture and gait must be maintained in the dark. Systematic movements must prevent dangers and damage as much as possible. Without the cooperation of groups of muscles throughout the whole body, it would be almost impossible to maintain an upright posture. In addition, the eyeball's principal task is to provide the brain with a steady picture on the retina, despite increased head movement. To this end, the visual axis of both eyes moves slowly in the direction of the bend before it jumps back in a quick, jerking movement. Medical science refers to these jerky eye movements as "nystagmus".

In order to keep moving images firmly in view, the human eye performs a sort of dance: three steps forward, one step back. This zigzagging is also useful in otological diagnosis. As far back as the turn of the century it had been noted that sudden changes of temperature within the ear actuated nystagmus. If the doctor rinses the external auditory canal (meatus) with cold or warm water, a rapidly ensuing nystagmus shows that the internal ear is healthy and functioning well.

Robert Bárány, a Hungarian physician who lived and taught in the former Austro-Hungarian Empire, was awarded the 1914 Nobel Prize for his explanation of the caloric or heat nystagmus. He made his conclusions by studying an old gas geyser. Heated liquid becomes light and rises. Cooler surface water, on the other hand, sinks. Liquid currents resulting from heating or cooling are generally known as thermoconvection. Any lymphatic fluid movement of this nature in the inner ear was bound to cause the sensory cells, and thus the brain, to imagine motoric stimuli. Although sitting quietly in a chair, the person concerned believes that he is rotating. To counteract this, the eye muscles receive nystagmic orders.

Robert Bárány's theory seemed highly convincing and was never questioned until the late Fall of 1983. Up to that time all experiments with the human sense of balance had necessarily taken place under the influence of gravity. True, nose dives in jet planes had created weightlessness, but only for a matter of seconds. Consequently, thorough investigations had been

impossible. Baumgarten's minnows had to act as the first "guinea-pigs" in 1973. These little fish react visually to the lack of gravitation with their whole body. They performed somersaults in Skylab for a period of three months non-stop. Once back on earth, however, they soon calmed down again and spent the rest of their days quite normally in a table aquarium.

But the decisive questions could really be answered only by humans themselves in a continuous state of weightlessness. If Bárány's theory were to prove correct, caloric nystagmus would not occur in space. Where gravitation is missing, there is no difference in weight between liquids of different temperatures and thus no fluid movements.

Von Baumgarten and his team designed a special experimental helmet for the tests in space. Since water atomizes in space, the helmet blows hot or cold air into the auditory canal of the person wearing it. Electrodes and sensitive infrared cameras, mounted on the helmet, register every movement of both eyes. The four astronauts, including Ulf Merbold, a German, took part in the nystagmus test and other equilibrium experiments for several days. Von Baumgarten supervised and controlled the experiments from the earth by radio.

Following certain adaption problems in the early phase of the experiments, the scientific sensation came on the third day: it was conclusively proved that caloric nystagmus also takes place during weightlessness. Bárány's 70-year-old theory was thus a matter of doubt, if not completely refuted. This test could only be undertaken in space and was made possible by Spacelab. Scientific experts in many countries are now seeking convincing explanations of caloric nystagmus. These, too, could be checked in space, as was shown by the specially designed vestibular slide used on the D-1 mission.

It cannot be ruled out that these findings may have a particular application on earth. Illnesses involving chronic vertigo, such as Menière's syndrome, stem from still unknown disorders of the lymphatic fluid in the inner ear.

The Spacelab astronauts became well aware of the value of

their balancing mechanism upon their return to earth, as, indeed, did all astronauts and cosmonauts before them. Their inner ear had gradually adapted itself to weightlessness in space. Once back in the earth's gravitational field, it occasionally failed to function during the first few days. As soon as the astronauts closed their eyes, or the light was extinguished, they were in danger of falling. The space travellers did have one pleasant after-effect though, for many months they were immune to any form of terrestrial seasickness. *Udo Schulz*

Incredibly tiny missiles, packed with energy, speed through space and could become a major problem for astronauts living on board a spaceship or station for prolonged periods. These "missiles" threaten to cut short the astronauts' stay in space. They are heavy ions or HZE particles. Although they represent a very small part of cosmic radiation, they can, even in small doses, cause permanent damage to living organisms:

Dangerous Mini-Missiles from Outer Space

A team of scientific experts, headed by Prof. Horst Bücker from the Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt, DFVLR (German Aerospace Research Establishment) in Cologne, sent specimens of biological systems on various space travel projects in an effort to explore the effects of particle radiation. The result of their studies was mentioned above. Following space flights with Apollo 16 and 17 and the Apollo/Soyus rendezvous, a biostack experiment was conducted during the 1983 initial flight of Spacelab, the European space laboratory, which lasted over a week.

Only one or a few of these oxygen, nitrogen, carbon or iron atoms, stripped of their electron sheath, hit one square

centimetre of the spaceship's hull during the course of one day. Even so, the energy-charged particles cause considerably more damage than the rest of cosmic radiation put together. The biostack experiments showed that cosmic radiation can be 200 times as intense as the radiation of energy-charged particles. Humans are protected from these dangerous missiles by the atmosphere around the earth and its magnetic field. The problem with the heavy ions is that they penetrate the walls of a spacecraft almost effortlessly. Only a steel plate, 130 centimetres thick, was able to stop these particles as effectively as the atmosphere does. It goes without saying that such heavy ballast could not possibly be taken along on space flights. Diverting the radiation from these charged particles by means of a permanent electric field would also represent a technically lavish undertaking.

By means of a special detection technique, Bücker and his team were able to register the traces of heavy nuclei during the biostack experiments. They were thus in a position to evaluate the radiation effect of each impact on the organisms and relate them to the physical properties (charge, energy, etc.) of the particles. Each of the biostack experiments contained a relatively similar selection of organisms representing various organisation levels with long storage capacities. These organisms included simple, monocellular bacterial spores (hay bacillus), plant material (carrots and goose grass, fungus spores), and highly complicated animal embryos (crayfish eggs). The impacts were recorded by so-called nuclear trace detectors. The traces obtained can be measured microscopically; they show which level of energy was released by the particles concerned, which organisms were affected, and how much damage was incurred.

The evaluation of the first three biostack experiments revealed that hardly one of the crayfish eggs was able to continue its normal development. Forty percent of the eggs showed no further development, while the remaining 60 percent had development disorders. Of all the crayfish eggs, only 14 percent developed into free-floating larvae. But even they

suffered from delayed growth: provided that they grew into fully-fledged crayfish, they had far fewer progeny than the control crayfish which had not experienced space travel. Malformations were ten times more frequent than in the control crayfish.

The plant seed and bacterial spores proved to be much more resistant, although here, too, anomalies occured. Only about half the bacterial spores produced living bacterial cells which were capable of growth and reproduction. There was evidence of tumours in plant germs and genetic damage (mutations) in maize. The experts explain the susceptibility of the crayfish eggs by the fact that they are already in a differentiated multicellular stage of blastulation. In such a stage, the functions of the cells, which have been destroyed through bombardment by heavy ions, can no longer be taken on by others.

The findings of the biostack experiments, however, cannot simply be transferred to humans, which never was the researchers' intention. Rather, Bücker's team wanted to assemble basic data on the biological processes involved in confrontation with heavy ions. Although these processes are more or less the same in human cells, the repair and control mechanisms between cells and tissue cannot be compared with those of the simple experimental systems. In the opinion of the researchers, for instance, the damage to human skin cells is not problematic since they can rapidly be replaced by new ones through the division of stem cells. It would be far more serious, of course, if these stem or mother cells were affected. The result would be a total breakdown of the replacement mechanism. Cerebral, spinal marrow or eye cells can neither be divided nor replaced. The question is how many such cells can drop out before a change in human beings becomes apparent. Here, the biostack experiments provided no answer.

Once the first three biostack experiments had exposed the previously unknown effects of heavy ions, the experiments carried out in Spacelab attracted the attention of the re-

searchers. They started to look for the possibility of combined effects of these particles with the main components of cosmic radiation and weightlessness. They also wanted to know whether the somewhat protective properties of the hull, inner parts, or the flight path of a spacecraft modify the findings obtained so far. To this end, the scientists provided Spacelab with four specimens instead of the one that went on the Apollo mission.

They were deposited in four different places, each of which provided a different level of protection: under the floor, behind the instrument panels, on the outside wall and, with absolutely no protection at all, outside on the pallet. The evaluation of the Spacelab flight has not yet been completed.

One fact has been ascertained already, though: as the experts predicted, Spacelab was exposed to much greater particle bombardment than the earlier flights of the Space Shuttle, which transported the laboratory into space. The dosimetric radiation readings showed that the bombardment was twice as intense. The reason for this is that Spacelab's orbit was at a higher angle of inclination to the equatorial plane, i.e. nearer the two poles. There, the earth's magnetic field did not divert the heavy nuclei very effectively. This dosimetric finding is of great importance for the researchers: it is obvious that the deliberate choice of a different trajectory might well reduce the concentration level of these cosmic mini-missiles on future outer space missions. Finding such a flight path is one of the major aspects of the biostack experiments. *Hans-Dieter Wolz*

As far back as some 100 years ago, Svante August Arrhenius, a Swedish chemist, assumed that organisms from outer space could have settled on earth and become the origin of all life on our planet. Even though this theory has still not completely vanished from scientific discussion, there are nevertheless very different reasons for the keen interest space biology has in the apparent hostility to life in cosmic space:

How Life Defies Outer Space

During the first flight by Spacelab 1983, Dr. Gerda Horneck, a molecular biologist and geneticist at the Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt, DFVLR (German Aerospace Research Establishment) in Cologne, checked on the possibility of organisms surviving such an inhospitable journey through space. She undertook these experiments with the international cooperation of several universities.

Her findings at this point are that robust forms in dormant state, such as hay-bacillus spores, are well able to withstand the torture of such environmental conditions. But there are certain reservations. The experiment demonstrated that they must be protected from high-energy ultraviolet (UV) solar rays lest this invisible light eliminates them. Human beings on earth are largely protected from ultraviolet rays by the ozone layer in the atmosphere.

Horneck sent between 100,000 and 10 million hay-bacillus spores distributed in various chambers on the space flight. The permanent forms were exposed either to a vacuum or sunlight of varying wavelengths in the ultraviolet range. This "blue light" kills germs and is used for this purpose on earth. With another group of spores no filter was used; they were exposed to the full force of sunlight and the complete UV spectrum. Further chambers were designed to examine the effects of a combination of these environmental influences. A simulation experiment under identical conditions was undertaken simul-

taneously at the DFVLR laboratory in Cologne.

Spacelab spent a total of ten days in space. The hay-bacilli withstood the vacuum on their own very well, at least in the simulation experiment. There still is no explanation why only half of them survived in outer space. Horneck suspects that when the shuttle carrying Spacelab re-entered the earth's atmosphere, the conditions for the spores were not particularly favourable. A small fire was visible, and hydrazine, a highly poisonous gas, emerged. In other words, resistant organisms could well withstand a space flight provided they have sufficient shade, even if there were subsequent mutations in the hereditary material. The incidence of mutation in the bacteria in the vacuum was ten times higher than under normal conditions.

The results of the experiment suggest that terrestrial organisms could be "imported" during a landing mission on another planet. This is why it seems that the current precautions by space-travel nations in regard to sterilising their landing vehicles is highly necessary. Although this measure is extremely costly, all countries engaged in space travel have signed an agreement to the effect that vehicles destined to land on foreign planets must be constructed under sterile conditions. In order to ensure that organisms do not find their way on board during launching, the landing vehicles are fitted with protective shields which are ejected into space. This is the only guarantee that the experts are able to explore other planets in their original state and to seek life forms there which have undergone their own development processes.

Unprotected spores on the outer skin of a spacecraft, however, stand absolutely no chance of survival. Gerda Horneck is now intent on finding out in further experiments to what extent a protective film or protective shade filters and moderates UV radiation. She and her colleagues are thinking of sending spores under a film of dust on the next space flight or in a layer so thick that those on the outside will provide protection for those inside.

The Spacelab experiment still leaves open the possibility that

germs from cosmic space find their way to earth. However, results achieved under certain experimental conditions need not necessarily correspond to real processes. In other words, the theory that life originated on earth through some sort of fertilisation from outer space has neither been refuted nor corroborated. In addition to the researched factors in the experiment, organisms face a further menace. Cosmic radiation, particularly heavy ions, could kill any organisms it struck. According to statistics, the permanent forms, protected from sunlight, could fly through space for a maximum of one million years before being hit and destroyed by radiation. This is why the travel-duration factor plays a role that is extremely difficult to assess. *Hans-Dieter Wolz*

3

Precise determination of time plays an important part in research and technology, as, indeed, it does in everyday routine. The difference is that scientific experts need to determine time much more accurately than we normally do in daily life when they are called upon to establish the exact position of a satellite. They measure how long light or a radio signal takes to cover the distance. The degree of precision required becomes more readily apparent by the fact that light or other electro-magnetic waves cover 30 centimetres in one billionth of a second:

An Almost Incredible Time Problem

Professor Philipp Hartl of Stuttgart University and his team have successfully tackled the problem of time synchronisation and determination of distances ranging down to one billionth of a second (nanosecond/nsec). Atomic clocks, which are the most accurate clocks currently available, coincide down to fractions of a nanosecond. In the case of these clocks, oscillations inside an atom keep time and are extremely immune to external interference. But in the past there was no synchronisation technique to ensure that these clocks are synchronous even over great distances such as between continents. Whereas synchronisation was possible down to a few nanoseconds within one continent, there was still a discrepancy of up to 40 nanoseconds between the US and Europe. In practical terms, this means that the position of a navigation satellite could not be determined down to an accuracy of under 12 metres.

But in experiments with geostationary telecommunication satellites, e.g. INTELSAT V, Hartl and his team succeeded in synchronising the time between Washington and Oberpfaffenhofen down to one nanosecond. In experiments with the first

communication satellite, OTS-2, which is owned by ESA (European Space Agency), the same team was able to carry out highly accurate position readings down to 30 centimetres without the aid of special equipment on board the satellite. The scientists used the MITREX (Microwave Time and Ranging Experiment) modem which they had designed themselves, and which they operated from the ground station. The system will now be further tested between stations in the Federal Republic of Germany and countries in other continents. The goal is to introduce the modem as standard equipment worldwide.

One technique in particular enabled the researchers to juxtapose a radio signal to transmissions via a telecommunication channel without reciprocal interference. This stems mainly from the reduced signal strength and the special form of what is being transmitted. The team developed a "pseudo-crackling", a sound similar to the background noise in radio communication systems, which repeats itself. This noise, however, is different from normal background noise in that it is predetermined both in sequence and form.

Sophisticated methods for processing electromagnetic signals at the receiving station "identify" the transmitted signal despite the diverse background interference. The signal is then further processed to the point where reliable information is obtained on the time-delay. At the same time accurate details can be determined on disturbing influences or influences distorting the time-delay, based on the form, signal strength, frequency, and phase. The device can be compared with someone learning a foreign language by trying to make out individual conversations in a room filled with whispering. If the person already knows the language quite well, he will understand individual words much better than someone with scant knowledge of the language. The longer and more frequently he listens, the more words he will understand because he can compare (correlate) them with his own vocabulary, thus grasping the meaning better. The machine "learns" in the same way: its method of correlation is observing the

countless goings-on and "identifying" a signal by comparing it with the "pseudo-interference".

The device must also allow for a number of other possible distortions. The air pressure, atmospheric humidity, temperature, frequency, and the time of day and year are of paramount importance for the time delay. The speed at which the waves travel is governed by the refractive index at that moment. Depending on the time of day and year, as well as on the solar cycle, reflections or scatter occur in the ionosphere. These, however, can be identified by their frequency-related behaviour. Even relativistic factors play a part in the realisation of maximum precision and have to be determined. The effects of aging transistors and crystal oscillators on circuits, or fluctuations in the main voltage also have to be compensated for by control engineering.

The scope for these new findings and techniques is endless. It will now be possible, for instance, to use telecommunication satellites much more efficiently because their position is known more precisely. The new methods also hold interesting prospects for navigational tasks. In the case of earthquakes, scientists must be able to measure down to one or two centimetres at a range of 100 kilometres. Hartl also anticipates simplification of practical geodetic (earth) surveying. By using methods such as MITREX, small, reasonably-priced devices could accurately and quickly survey a house via satellite down to one centimetre. Navigation satellites also offer an opportunity of surveying water surfaces in the same way as oil-prospecting. ERS-1, the first European remote sensing satellite, will be used for these and other projects. The Stuttgart team is already preparing an experiment to succeed MITREX for time and velocity ranging. *Hans-Dieter Wolz*

Predictions continue to remain noncommittal on the climatic repercussions of the steadily increasing carbon-dioxide content of the earth's atmosphere and the possible evaporation of the ozone layer providing a protective shield against ultraviolet radiation. A lot of these predictions are necessarily mere speculation since accurately measured data by satellite survey of the earth is not available:

The Blue Planet's Air to Live

The reason for this lack of data is that the sky merely appears to be within easy reach of the scientists, but in reality it is not. They may be able to launch their instruments into the atmosphere with a balloon and bring back a few litres of air for laboratory tests – but that's all! The sparse findings gleaned in this way do not permit qualified statements to be made on such complex processes as the "heating-up" of the atmosphere through gases or the reduction in the ozone level through chlorinated hydrocarbons. These measurements all have the same shortcomings: the data obtained only provides information about a limited area at certain times, but not about worldwide distribution and seasonal changes.

The Federal Ministry of Research and Technology has therefore promoted the development of three probes which will one day be taken into outer space as a payload on board an unmanned satellite. From its earth orbit it could provide precise details for years on trace gases in the atmosphere at a height of between 20 and 100 kilometres and on the state of the earth's radiation.

The Meteorological Institute at Munich University, for example, is carrying out an experiment called MIPAS (Michelson Interferometer Passive Atmospheric Sounding). This probe analyses the incident light spectrum, using the interference phenomenon as a basis: interference light waves intensify or weaken according to their phase-shifts. For this purpose, MIPAS needs a semipervious plate, which splits the ray of

light, and two mirrors at different distances, which eventually rebundle the light again. In order to cover the whole light spectrum, one mirror must be mobile.

The layers of light striking the probe laterally are used as an indicator element for trace gases in the atmosphere. Depending on their type, these gases absorb a specific wavelength, i.e. a certain portion of the light's colour, which is proven by MIPAS and evaluated by computer. The accuracy is so great that one tenth of a part to one billion parts can be registered. A new feature is the "double pendulum" which, with the help of magnets, controls the mirrors more precisely and more quickly than the electric motors were able to do in the past.

Similar goals are being pursued by MAS (Microwave Atmospheric Sounder) at the Max-Planck-Institut für Aeronomie (Max Planck Institute of Aeronomy) in Lindau/Harz. However, this device analyses the characteristic electromagnetic waves emitted by gases such as nitric or sulphurous oxide. It systematically scans incoming radiation along the familiar gas lines and thus achieves a measuring accuracy similar to that of MIPAS. NASA, the U.S. National Aeronautics and Space Administration, has already announced that it is ready to test the device free of charge on the next earth exploration mission by a satellite, which is scheduled for 1988 at the earliest.

The CSR (Conical Scan Radiometer) of the Department of Geophysics and Meteorology at Cologne University was designed to measure the earth's radiation balance. It registers both the incident sunlight on earth and the heat radiation produced. Although weather stations have long been able to do this, they could only do so from certain angles. Since, however, heat is emitted in all directions, the results are inadequate. The CSR does allow for the diverse angles of reflection. In collaboration with French experts, the CSR will be further developed; it will be tested as an aeroplane version on board a jet in the near future. It is to go into operation in space on board a French satellite in 1991. The readings obtained could then offer basic information on whether there is really a changed hot-house effect. An indication of this would be given if the

earth radiated heat from different altitudes into outer space over a prolonged period.

The characteristic feature of these probes (sounders), apart from the length of time it takes to develop them, is their cost. The time it takes to develop a laboratory model into a machine which can be used in space is eight years; the research process costs DM 30 million. Although these devices are, in principle, equipped with the latest measuring techniques, they have to withstand far greater acceleration than exists on earth. Furthermore, their component parts must not slip by even one thousandth of a millimetre if the enormous cost involved is to pay off. The slightest changes of this nature could distort all test readings and render the whole project useless.

The probes themselves weigh one to two tons each, including such supply systems as power, cooling and control. The launching alone, if it had to be paid for, would come to several million DM.

But the expense is well worth it: it will help provide reliable information on whether the level of gases in the atmosphere, such as nitric or sulphurous oxide and, of course the gases used in spray cans, is increasing, which might lead to a possible long-term change in the climate. These substances stem mainly from industrial chimney stacks, house chimneys and automobile exhausts. A reduction in ozone concentration has already been established by conventional methods at a height of 40 kilometres. This is why exact measurements seem highly necessary if we are to be in a position to avoid a worldwide catastrophe by adopting timely countermeasures.

Dieter Schwab

Exploration of the earth via satellite has prompted researchers to resume the age-old tradition of exploring the Antarctic. By using new methods, geodesists have already produced many a cartographical masterpiece of that grandiose but treacherous continent:

"Unveiling" Antarctica

New Schwabenland is situated on the edge of Antarctica, surrounded by gigantic ice sheets and high mountains. It is one of the most hostile regions in the world. It owes its somewhat romantic name to a team of German researchers who, as members of an Antarctic expedition, arrived there in January 1939. Their ship, the "Neuschwabenland", was a catapult ship belonging to a company at the time known as "German Luft Hansa". It was equipped with two flying boats converted to carry out survey flights. Under the leadership of Alfred Ritscher, a marine captain and pilot experienced in travelling in the Arctic region, the team of researchers on that expedition were given the task of exploring and surveying part of the Antarctic continent from the air.

For this purpose, both flying boats had been outfitted with aerial survey cameras which were constructed in such a way that they could take overlapping photographs when flying over an area in a straight line. The final result was 11,600 oblique aerial photographs, including a large number of individual shots and two ciné films. The two flying boats spent a total of 57 hours in the air and covered a distance of 7,700 kilometres on their mission. In just three weeks, the pilots and aerial photographers surveyed an area twice the size of the Federal Republic of Germany.

The German researchers were only partially able to realise their main objective, i.e. drawing a topographical map of the entire area of New Schwabenland with a scale of 1 : 250,000. Even so, they made a major contribution to what Professor Heinz Schmidt-Falkenberg, a geodesist at Frankfurt University, calls the "unveiling of Antarctica". James Cook, a

Briton, was the first to penetrate the south polar circle during his exploratory voyage of 1772–75. On his return from the Antarctic Ocean, he destroyed all illusions about there being a huge, fertile continent at the South Pole. Nevertheless, whale catchers and seal hunters, whose curiosity had been aroused by Cook's accounts, moved farther and farther south into the rich fishing grounds. They were most likely the first human beings to set eyes on the Antarctic mainland. Officially, according to a court ruling, this honour is enjoyed by Edward Bransfield, an Englishman.

German activities in the land of the penguins began with the Eduard Dallmann Expedition in 1873/74. Prior to the big expedition in the summers of 1938/39, ten other exploratory voyages to the South Pole had been undertaken. "Prinzregent-Luitpold-Land" or "Kaiser-Wilhelm-II-Land" are reminders of these German expeditions. In a digital card index the Frankfurt Institute of Applied Geodesy has registered 600 German names in Antarctica. German names can be found on maps of Antarctica, together with the geographical names given to various regions by explorers from other nations. Schmidt-Falkenberg states: "They bear witness to the scientific efforts and research activities undertaken by the various countries."

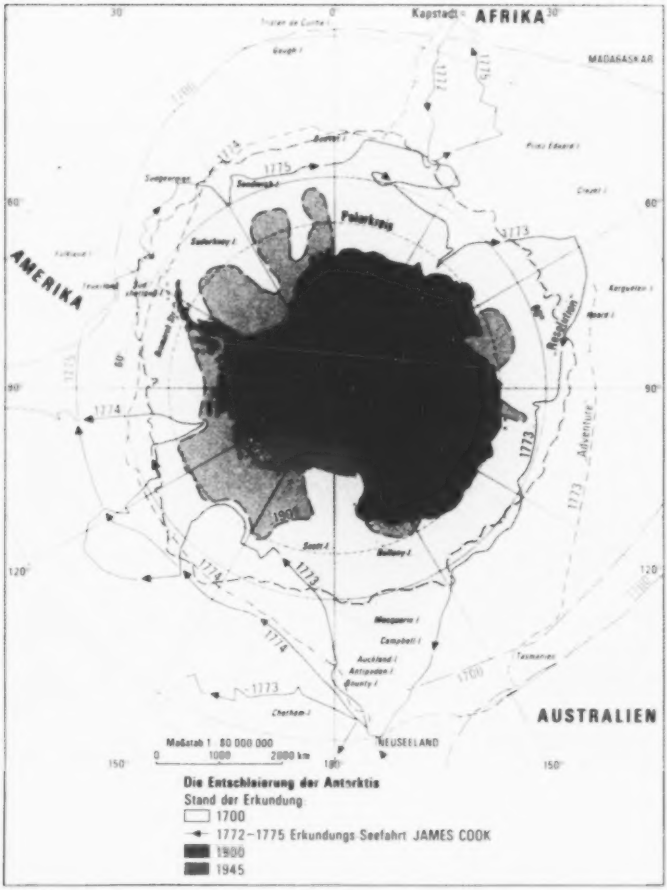
International teamwork has been going on in the Antarctic since the late 1950s. At the time, twelve countries signed the Antarctic Treaty in which they pledged to use this sixth continent for peaceful purposes only. The treaty marked the beginning of the race for mineral resources in Antarctica, even though their exploitation is still regarded as uneconomical.

After an interruption of some 40 years, the Federal Republic of Germany began to participate in the scientific exploration of the Antarctic again in the late 1970s. Things happened in rapid succession. In 1979 the Federal Republic of Germany became a signatory country to the Antarctic Treaty. Two years later it became a member of the all-important consultative body. In that same year it joined the research work being carried out at the "Georg von Neumayer" research

base, a research station on the coast of New Schwabenland which is manned throughout the year. The "Antarctic Research Programme of the Federal Republic of Germany", which currently includes 70 projects, was approved by the federal government in Bonn. Thus, within a very short time, the Federal Republic of Germany assumed a major role in research activities at the South Pole. Topographical and geographical maps are needed if German research projects in Antarctica are to be carried out successfully. Only by means of the latest details can safe land routes into a particular expedition area be explored and decisions concerning the setting up of intermediate camps be taken. Reliable information must also be obtained on site in order to set up possible landing strips for aircraft fitted with skids. Maps must be available. And finally, research findings have to be geographically accurate.

The scientific staff at the Frankfurt Institute of Applied Geodesy have developed a two-fold approach to the task of drawing maps of the region: they are using satellite and aerial photographs. For the first time since 1939, German aerial survey was resumed in 1983/84 during the Antarctic summer. 1,800 photographs were taken from the air by Polar 2, an aerial survey aircraft of the Dornier 228–100 type. The Frankfurt geodesists scheduled the flights for the western part of New Schwabenland, which is the area where the "Georg von Neumayer" base is located. The aerial photographs are currently used to produce maps to the scale 1:50,000.

A series of maps of New Schwabenland have been drawn in the last three years on the basis of satellite photographs. The Frankfurt geodesists' masterpiece is a unique satellite map (scale: 1:6,000,000), taken at a height of 800 kilometres and providing an overview of the Atlantic half of Antarctica. The particular feature of this map is the fact that it consists of eleven "scenes" shot at different times. The photographic data were supplied by the NOAA satellite. Whereas aerial photographs taken from aircraft are analogous, satellites provide digital, computerised pictures. These can first be processed



Photographs taken by satellites and aerial survey planes are a valuable contribution to the "unveiling of Antarctica", started by James Cook, the first person to penetrate the southern polar circle. (Photograph: H. Schmidt-Falkenberg, Institut für Angewandte Geodäsie, Frankfurt/Main).

(optimised) and then converted into analogous reproductions by computer.

The basic requirement for satellite photographic maps are control points, i.e. points in the photo which are identifiable and whose coordinates are known. Consequently, with the help of existing and usable maps, the Frankfurt cartographers set up a topographical control-point card index. This index is meant to ensure that photographic maps of the Antarctic can be reproduced with geometric accuracy at any time in the future.

The experts were faced with a problem, however: the format of the original NOAA satellite's magnetic tapes was different from the format normally found in photographic processing. A special data processing programme had to be developed to convert the original 10-bit photos into 8-bit photos. The loss of information which resulted from this conversion is negligible as far as the map users are concerned since the human eye can only make out about 40 shades of grey. The 8-bit version features as many as 250 shades of grey.

On the other hand, the contrasts on the photographs of mainly ice- and snow-covered areas had to be improved. Using mathematical procedures, the researchers in Frankfurt managed to create an optimal scale of shades of grey, at least for the major mainland areas.

In order to compensate for distortion effects (panorama distortion etc.) the experts took advantage of the fact that the satellite photographs overlap considerably in parallel orbits over the Antarctic continent. As a result, the cartographers were in a position of being able to use largely central photographic areas.

Rüdiger Jungbluth

It is a well-known fact that modern satellite imagery, taken with special detectors, can be enlarged to such an extent that the most minute details of the earth's surface can be identified. It can even be discerned what the headlines in a newspaper read, or whether the reader of the newspaper parts his hair on the left or the right. These technological wonders really do exist and promise enormous benefits for the Third World:

Eagle Eyes in Space

Normally, terrestrial exploration by satellite is restricted to identifying much larger schemes. This is the important advantage of this technology. Vast areas of land, some 35,000 square kilometers in size, can be overviewed fairly regularly. Admittedly, the satellite pictures do not provide as much detail as conventional aerial photographs, but they are faster, far more up-to-date, and much more economical. Finally, satellite imagery offers much more information than the results of a geoscientific exploration project.

On behalf of the Bundesministerium für wirtschaftliche Zusammenarbeit (Federal Ministry of Economic Cooperation), the Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources), Hannover, carried out an extensive survey using satellite imagery of the African Republic of Upper Volta (Burkina Faso). It was shown that the interpretation of satellite imagery (particularly of imagery taken at various times of the year over the territory in question) is "orbitally" superior to all other methods, even when such interpretation has to be verified on site by random checking. In the case of the Upper Volta project, the ground check took only two months.

The goal of this project was to gather information beyond that in existing publications and maps by evaluating a wealth of satellite imagery. Accurate details were to be obtained in the fields of geology, pedology, land use and hydrogeology. These are fields which are by no means of purely theoretical

importance to Upper Volta, a country which is situated in the Sahelian Zone south of the Sahara. It should be borne in mind that shocking reports of drought and starvation in that part of Africa have gone around the world for years. That news made it patently clear how much effort is necessary to improve substantially the supply of water and agricultural products to the population.

Naturally, efforts on this scale depend on reliable information about natural water resources as well as the composition and quality of the soil. Productive planning cannot be undertaken until this data is available. For example, knowing where water can be found is not sufficient. Further details concerning the properties of the soil and the basic irrigation possibilities of the site must be taken into consideration to avoid faulty and costly planning. Here, the use of earth observation satellites seems to have developed into a highly informative procedure which is also economical. The report on Upper Volta states that "satellite images provide a quick overview and make major relationships apparent in the landscape."

The Republic of Upper Volta can now be provided with systematic information on potential ground water reserves in particular and natural resources in general. In addition, an astonishingly differentiated analysis of the composition of the soil shows where it can be best exploited for agricultural purposes in the future. For the first time ever, a comprehensive and clearly classified ground map was prepared covering the region.

This success was made possible by LANDSAT, a satellite especially designed to explore ground resources. It orbits the earth at an altitude of 900 kilometres. As required, it can image the entire surface of the earth every 18 days. This is accomplished in the first instance by a TV camera which transmits black-and-white images of relatively sharp detail to a ground station. At the same time, a scanner continually scans the earth's surface in lines in a 185 kilometre swath and provides digital data as an end product. Even the smallest differences in vegetation are registered. However, in order to

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interpret these images geologically or pedologically, precise knowledge of the climate and land exploitation is required even more than is necessary to understand aerial photography.

The scanner transmits no fewer than 7.5 million data per frame for four different wavelengths of the visible spectrum, ranging from green-yellow to infrared. The smallest image unit is 79 × 56 metres: in other words, a newspaper would have to be that large to be registered by the LANDSAT scanner. However, the sharpness of the image is adequate for the finest soil analyses. This, at any rate, has been substantiated by geoscientists D. Bannert, R. Hoffmann, H.-P. Jöns and W. Kruck in the final report on the Upper Volta survey. The methods used there, the starting points and the results of the project are carefully explained in the report. There are also various maps which were compiled using LANDSAT imagery and which emphasises specific interpretations. These include geological and pedological aspects, the probability of mineral resources, information for ground water research, and improved exploitation of the surface water in natural and artificial lakes. Settlement density and actual land use are also shown on six maps.

A seventh map provides several detailed surveys covering population density, soil quality, workability of the soil, and ground water probability. It provides a clear picture of land development potential for future planning and is a useful aid for a current settlement programme covering viable areas of the country.

Lasting changes are also unavoidable. The satellite images of Upper Volta show considerable degradation of vegetation due to extensive animal husbandry and the agricultural methods used: overgrazing, uncontrolled deforestation, and land clearance by burning expose the soil to wind erosion and result in a considerable loss of nutrients. Some 80 million tons of feed are burnt annually. However, the final report does not conceal the fact that for people living on the southern edge of the Sahara, no alternative has as yet been found to shifting

cultivation by using fire to clear land and burning off pasture. This is because primitive agricultural implements do not permit any other form of clearing the land.

Thus, satellites play a diagnostic role in this field: they do not offer a remedy but they do indicate possible opportunities and ways of improvement, as in the case of the Republic of Upper Volta. Moreover, satellites are instruments for continuous control. It can be determined whether afforestation assists in halting the problematic spread of the desert, or whether a possible prohibition of land clearance by burning is in fact observed. With their sound knowledge of satellite image interpretation, the experts at the Federal Institute for Geosciences and Natural Resources provide optimal support for regional projects of this type. The fact that earth observation satellites help to promote thought in wider dimensions gives rise to hope for our planet; and this is reason enough to send scientists into space. *Uwe Andresen*

It was for an important symbolic reason that the capital of Tanzania was moved from Dar es-Salaam to Dodoma in 1973. The new capital, still somewhat rural in appearance, is located in the middle of the country. The planners want it to become the central point in every sense of the word one day. Remote survey by satellite has already provided valuable infrastructural help for the whole country in its journey along the road from symbol to reality:

Satellite Data for Tanzania

This complex scheme has confronted Tanzania with a major infrastructural problem. Therefore, a project entitled "Integrated Development Plan", which took several years to prepare, was launched for the Dodoma region by the UN in mid-1983. It is meant to explore the agricultural potential of the Dodoma area and, on the basis of the information obtained, set up concrete development projects such as the construction of irrigation plants. The area surveyed (41,000 square kilometres) is about the size of the Netherlands.

An engineering firm from the West German city of Essen, Agrar- und Hydrotechnik (AHT), was contracted to implement the UN project. It soon turned out, however, that a survey of the area would take much more time than originally planned since there were no maps of the Dodoma region with a scale large enough to serve the purpose. Consequently, AHT suggested to the UN that satellite photographs should be used as basic material for the Dodoma region survey.

Anyone can order satellite photographs for a few hundred German marks. The main problem, however, is how to evaluate the satellite data. It is important to note that the photographic method used by satellites differs considerably from normal photography: satellites have only a limited number of frequency ranges, known as "channels", to make their observations. They see some colours very well, but are blind as far as others are concerned. Moreover, the information obtained is not recorded on film but transmitted as

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individual values to ground stations where it is stored on magnetic tapes. There is one such ground station in Johannesburg, South Africa. This ground station was asked to supply magnetic tapes of the Dodoma area which have been photographically recorded by the LANDSAT 3 satellite.

LANDSAT 3 which belongs to the American space agency NASA orbits the earth at an altitude of 900 kilometres, almost vertical to the equator. It surveys the earth's surface with a multispectral scanner. This scanner consists of several detectors which register the strength of the solar radiation that is reflected from the earth's surface in three channels: green, red and two ranges of infrared. These detectors scan an area 185 kilometres wide. If conditions are favourable enough, they can even distinguish between objects no more than 80 metres in size.

The main problem was converting these satellite photographs on magnetic tape into pictures with which lay persons could work. This process is of paramount importance for the use of satellite data.

The easiest way of converting the information contained in the three channels into pictures is to make black-and-white photographs. Thus, the grey shades of each photograph can be related to the radiation intensities recorded on each channel. The differences between the photographs are too minimal, however, and three pictures of this kind are too comprehensive for practical purposes.

Copying the three individual photographs via three colour filters onto one colour film is a further development of this technique. In this process infrared is marked by the colour red, red by green, and green by blue. In other words, photos with wrong colours are created. The intention of this distortion is to retain colour combinations which are as easy to analyze as possible. The analysis of a particular shade is supposed to permit conclusions to be drawn on the basic colours and thus on the original spectral course of the three channels. The drawback of this method, however, is that the difference between the colour combinations of the three

channels is not sufficiently marked.

One photographic process enhancing these differences is the ratio technique. The intensity quotients of two channels are calculated with a computer and reproduced on a black-and-white photograph. If a red/green ratio picture is made, the lighter areas indicate a preponderance of green, and the darker areas a preponderance of red. The quotient formation in the ratio technique guarantees that there is excellent differentiation between the three channels. The main disadvantage of this process is that the intensity is determined rather than the absolute ratio (1 : 2 may mean both 0.5 or 3 : 6). Also, there are three photographs again instead of one: green/red, red/infrared, and green/infrared.

Dr. Rupert Haydn, a former researcher who now is with the Gesellschaft für Angewandte Fernerkundung, GAF (Society for Applied Remote Sensing), has developed a universally applicable method to combine these three types of information in one colour photograph. He calls it the "IHS Ratio Method" since it is based on the IHS colour theory using ratio photographs. IHS is the abbreviation of the three English words "Intensity", "Hue" and "Saturation". Each of these three factors is perceived independently by the human eye.

The intensity represents the strength of the reflected light. The hue is characterised by the frequency: if one takes a rainbow spectrum, the colours have an increasing light frequency, from red to orange, yellow, green, blue, to violet. The somewhat unfamiliar term "saturation" can be easily explained by the reverse procedure of mixing white with another colour: red, for instance, has a greater saturation quality than pink, even though at first it seems that the saturation is not dependent on the intensity. This is best illustrated by remembering that traffic signs in fluorescent red reflect more intensively than pink or completely white objects.

The independent nature of these three factors makes it possible to encode, as it were, the three sets of details in one colour picture. The advantages of various photograhic processing techniques are thus combined in one single photograph.

The IHS method was used for the processing of the satellite photographs in the following manner: the average intensity of the three channels was represented in the IHS photograph by intensity, the green/red by the hue, and the red/infrared by saturation. Colours of higher frequency therefore mean that the green channel dominates the red, and vice-versa. Colours with a lower saturation level display a preponderance of red as opposed to infrared, while colours with greater saturation properties have predominance of infrared. The absence of a green/infrared ratio photograph is unimportant since it can be substituted by the other ratio pictures.

The IHS method is, of course, only one of several photographic processing techniques today. Even so, it is one of the most promising methods. Its great advantage is that the three components, intensity, hue and saturation are completely independent from one another. This makes the method extremely flexible.

But the question remained as to how the experts were able to obtain useful information from the IHS photographs of the Dodoma region. Basically, it can be said that the intensity pattern of a photograph provides information on a particular area's relief and the ratio pictures on the nature of the soil and vegetation. This evaluation is based on the known frequency-response values of certain plants or soils. Plants, for instance, can be indentified through a marked maximum in the infrared range. (If humans were able to perceive infrared, they would see all plants in infrared rather than in green). Since fresher, healthier plants have stronger infrared reflecting properties than dried-up ones, it is even possible to draw conclusions on the state of vegetation in a particular area.

Although empirical knowledge permits the gleaning of such information from a satellite picture, the experts still do not have enough experience with using these kinds of photographs to interpret them fully. They still have to do field research to compare the photographs with reality. It is only in this way that geological findings of a more profound nature are possible because satellites can only record reflections on the earth's

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surface. Since the UN had not originally planned to use satellite photographs for the whole project, AHT experts commissioned to evaluate the IHS pictures had very little time at their disposal. They had a bare two weeks to get to know the Dodoma region which covers 41,000 square kilometres!

One of the team's experts was put in charge of preparing a map which classifies the individual structures in the IHS photograph. He found 14 different geographically homogeneous ground units corresponding to specific patterns on the IHS picture. He was, of course, unable to undertake a strictly rational classification given the time constraints. Consequently certain ground units were characterised by their vegetation, type of soil, etc.

Another scientist concerned himself with Tanzania's ground water reserves. Due to limited rainfall in this region, shortage of water is one of the biggest problems. His task was to prepare a map showing the areas where drilling projects would be most likely to strike ground water.

In summing up the results of this use of satellite data for the Dodoma project particular mention must be made of the high level of efficiency resulting from technology transfer between university research and practical application in a limited period and at little expense.

It goes without saying that the Dodoma project has by no means been concluded as a result of this preliminary geographical activity. Concrete regional projects are now to be started based on the information obtained. The Tanzanian government even intends to use the satellite photographs to set up a poultry farm. *Philip Erdös*

Scientists today are able to put their invisible tape-measures around Mother Earth's belly with fantastic accuracy. Nothing can escape the geodesists' attention, not even when points on the earth's surface, thousands of kilometres away, are displaced by a few centimetres. The experts can now call on the help of a radio telescope in Wettzell in the Bavarian Forest. Its antenna is 20 metres in diameter.

Taking Measurements of Mother Earth

When Sir Francis Drake, the renowned British seafarer, compared the vegetation of Africa with that of South America, he was undoubtedly the first person to conclude that the earth's face is subject to change. This insight experienced its major breakthrough in 1912 when Alfred Wegener, the German polar explorer, published his theories on continental drift. According to this theory, all the continents must be regarded as parts of a huge continent which, so to speak, are drifting apart. Parts of South America, Africa, India, Australia and Antarctica are all fragments of the landmass of Gondwanaland.

Today, the continental-drift hypothesis has been substantiated by means of plate tectonics. Accordingly, the earth's crust consists of a number of continental-size or smaller plates which shift and twist in relationship to one another by a few centimetres every year. In the 60,000-kilometre break-up zones beneath the seas, new oceanic earth crusts are formed constantly; old oceanic earth crusts are submerged and smelted at those points where the continents touch one another.

Volcanism and frequent earthquakes characterise the places where they appear and disappear. This is impressively illustrated by Iceland, the volcanic island located in the Atlantic trench. These processes and the question of how to forecast them accurately are of interest to geologists as indeed are all

the mechanisms which keep the face of the earth in dramatic motion. The earth's rotation and the tides are good examples of these dynamic processes.

Today, it is possible to make accurate measurements of the earth's surface by tracking the orbits of artificial satellites. Laser pulses are sent back and forth between them and the earth, creating a sort of optical echo-sounding. The predominantly near-earth orbits of satellites equipped with retroflectors are disturbed by the earth's irregular internal mass distribution. The calculated extent of these disturbances has confirmed, among other things, that the earth is by no means spherical; it rather has the shape of a pear (geoid). The diameter of its flatter South Polar underside to the North Pole is 43 kilometres shorter than its diameter at the equator. Mean sea level is also not quite what it was thought to be: the sea level off India, for example, is about 110 metres lower than elsewhere; near New Guinea it is 90 metres higher.

Interferometry, made possible by using radiotelescopes, has turned out to be a highly promising way of surveying the earth over great distances. A high-performance instrument has now been set up in Wettzell, Bavaria. This telescope was financed by the Deutsche Forschungsgemeinschaft, DFG (German Research Association) and the German Federal Ministry of the Interior as part of the Special Collaborative Programme on Geodesy.

As the basis of their measurements, radiotelescopes use the radio signals of distant, strongly radiating astronomical objects, e.g. quasars. Such a telescope should not be regarded as a single "independent" antenna, but as part of a system which can be extended over vast areas of the earth. Only when at least two radiotelescopes are used very far apart can the distances and the changes these distances undergo in the course of time be determined. These data can be concluded from the delay differences of the radio signals emitted by these astronomical objects. The normal procedure is to measure the signals coming from a larger series of these "radiators".

Theoretically, this technique, known as Very Long Baseline

Interferometry (VLBI), is accurate down to the last centimetre when measuring distances and down to several thousandths of second of arc when measuring angles. One of the basic requirements is that the telescopes work simultaneously. This is achieved by standard frequencies which fluctuate less than one billionth of a second in fifteen minutes. These super-precise time markers are recorded on computer tape together with the radio signals. The tapes containing the data of all the telescopes involved are then evaluated jointly. This is being done by a team at Bonn University's Department for Geodesy as part of the Special Collaborative Programme on Geodesy.

The Wettzell telescope began operations in mid-1983 on a 919.661-kilometre-long base line to a radio telescope in Onsala, Sweden. It achieved an accuracy down to one centimetre. Since early 1984 this 20-metre radiotelescope at the fundamental station in Wettzell has been used on a regular basis for several international projects with a geodynamic objective. By late-1985, some 140 experiments examining the rotation of the earth had been carried out. Each of these experiments lasted 24 hours and was carried out every five days by telescopes in Westford, Fort Davis and Richmond (all US), and Onsala. In addition, readings are taken daily at 60-minute intervals in collaboration with Westford. These readings, which will be taken for a period of about 12 months, are designed to detect marginal fluctuations in the earth's speed of rotation.

The Wettzell station has also scored an extraordinary success in a series of experiments which were part of a project coordinated by NASA, the U.S. National Aeronautics and Space Administration. These experiments dealt with the dynam-

The powerful laser at Wetzell Station tracks and measures special geodetic satellites in the sky like an optical echo sounder. The orbital disturbances of these satellites permit the recognition and determination of measuring irregularities of the earth. (Photo: Institut für Astronomische und Physikalische Geodäsie der Technischen Universität München)

ics of the earth's crust and earthquake research. The distance to numerous stations (up to 10,000 kilometres from Wettzell) has now been determined exactly, down to a few centimetres. In two to three years, conclusive evidence of plate movement across the Atlantic may well have been obtained.

Rolf H. Simen

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After an interruption of several years, the launching of EXOSAT in 1983, the European X-ray satellite, gave astronauts the opportunity once more to investigate celestial bodies in the light of energy-rich X-rays, i.e. radiation providing information on the violent and catastrophic changes in outer space. ROSAT, the new German X-ray satellite which is scheduled to go into orbit in 1988, promises even greater research opportunities:

Looking at the Universe with X-Rays

For a long time scientists had but limited means of observation. They were restricted to the reception of visible light which, however, is only one tiny fraction of the electromagnetic spectrum. Only 40 years ago astronomers began to venture into neighbouring areas. Whereas radioastronomy can be undertaken on the ground, the earth's atmosphere, because of its filtering effect, makes it impossible to observe shortwave ultraviolet and X-radiation.

In the early days, astronomers made use of high-flying balloons equipped with measuring instruments which were able to collect partial evidence of energy-rich X-radiation. These projects were supplemented by high-altitude research rockets which transported X-ray detectors into the area beyond the earth's atmosphere for some minutes.

Since 1970, X-ray astronomy has been greatly assisted by satellites orbiting the earth. Using the American satellite Uhuru, scientists found several hundred radiation sources in the sky. The Einstein Observatory HEAO-2 was able to make out several thousand sources by the late 1970s. Many of these objects have since been identified as quasars, X-ray pulsars, or even active galactic nuclei. Behind many of these, the experts suspect the existence of the mysterious Black Holes, the extreme final stages of stellar development.

The desire of many Europeans to have their own X-ray satellite started to burgeon soon after ESA, the European Space Agency, had been established. An agreement to construct an X-ray laboratory was signed by ESA and Messerschmitt-Bölkow-Blohm (MBB) in 1977. Within a few years, a research satellite was developed in Ottobrunn near Munich, which was capable of observing known X-ray sources and discovering new ones with its four detectors.

It operates with two reproductive X-ray telescopes having a 30-centimetre aperture, the theory for which was developed 30 years ago by Marburg physicist Hans Wolter, a proportional counter, and a gas-discharge counter for energy-rich X-radiation. The data obtained provides information about the location of sources, their structure, spectral composition and temporary changes in radiation. In addition, there are plans to use this data to compile a space atlas.

The energy supply for the measuring instruments and air-conditioning is provided by four solar panels, designed and constructed by AEG-Telefunken, Hamburg. They have an output of 320 watts which, by means of a control unit, can be converted to a distribution voltage of 28 volts.

In order to locate X-ray sources as accurately as possible, the scientists have developed a sophisticated procedure: they use the moon as a sighting device, so to speak. The relative position of the satellite and the moon always results in an eclipse by the moon: one of the sources of radiation relative to the satellite disappears behind the edge of the moon and reappears a little later on the opposite side. If the exact positions of the probe and the moon are known, the celestial coordinates of the X-ray source can be determined by the precise points in time of the X-ray eclipses. The more pronounced the satellite's trajectory is towards the moon, the

Model of ROSAT, the German X-ray satellite, which will go into orbit in 1988. (Illustration: MPG/Schäfer)

greater the area of the sky which can be covered by the moon in the course of time. Consequently, EXOSAT has been given a path angle of 75.5° to the equator. In order to ward off interference from the Van Allen radiation belt, the satellite describes a marked elliptical orbit which takes it as far as 200,000 kilometres away from the earth. One orbit takes 96 hours, 80 hours of which can be used as pure measuring time, including constant observation of one single source. EXOSAT has been operating successfully in outer space for almost three years. During this period, 1,500 observations of X-ray sources have been made. The researchers' demands continue to run at a high level.

The scientists from the Federal Republic of Germany participating in the experiments come from Tübingen University and the Institute of Extraterrestrial Physics, part of the Max-Planck-Institut für Physik und Astrophysik (Max Planck Institute of Physics and Astrophysics) in Garching near Munich. But above and beyond the German scientists' involvement in this research area, the researchers in Garching are working intensively on the next X-ray satellite, ROSAT, which will be launched as an all-German project in 1988.

ROSAT will be designed by the Dornier System company on behalf of the German Federal Ministry of Research and Technology, which is represented in this project by the Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt, DFVLR (German Aerospace Research Establishment). The two other firms involved are MBB/ERNO and Carl Zeiss, Oberkochen, which will develop the mirror system. The Max Planck Institute of Physics and Astrophysics bears the overall responsibility.

The systems in the new space vehicle will be able to make out X-ray objects with a degree of accuracy vastly superior to all current techniques. The experts anticipate that no fewer than 100,000 previously unknown X-ray sources will be discovered. The object of the ROSAT mission is ambitious: for the first time, a comprehensive survey of the heavens will be undertaken with a reproductive X-ray telescope.

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ROSAT will be launched on a space shuttle flight: this means that the largest X-ray telescope ever to be built will make its début. It has an aperture of no less than 83 centimetres. With a sensitivity level never achieved before, it can reproduce images in four energy areas of X-radiation, in four different invisible colours, so to speak, which then will be converted into visible colours. This will provide the scientists with much more information than any black-and-white system could. Professor Joachim Trümper, Max Planck Institute of Extraterrestrial Physics, says that for the first time a degree of sensitivity and definition has been achieved for X-radiation in Europe equal to that which is the accepted norm in optical and radio astronomy.

Trümper comments on this highly ambitious project: "The differences between the first X-ray detectors in 1982 and the ROSAT telescope can be roughly compared with the telescope used by Galileo in 1610 and the modern optical instruments such as the Max Planck Institute of Astronomy's 3.5-metre telescope on the Calar Alto in Spain."

But the comparison does not stop there: the ROSAT-Wolter telescope consists of four nested parabolic-hyperpolic reflectors made of zerodur, a ceramic material developed by Schott Glaswerke, Mainz. This material, which has already been used for the large-scale mirror in the Calar Alto telescope and a number of other reflecting telescopes, retains its form despite fluctuations in temperature: it neither contracts in the cold nor does it expand in the heat. The optically active X-ray surfaces of this mirror, which is ground and polished by the Zeiss company, have received gold-vaporisation treatment, which improves the reflection of the X-rays. The surface of the mirrors comes to almost nine square metres. Thus, they have almost the same dimensions as the 3.5-metre reflector on the Calar Alto. But it should be noted that the demands placed on the micro-roughness of the X-ray mirrors' surfaces are much higher.

The equipment is ideal for "soft" X-radiation in the 4 to 100 Ångström wavelength area. Wide counter-detectors continue

to be the only means of observing shortwave radiation. Even so, the accuracy of the Wolter telescope is in the region of a minute of arc, i.e. better than the human eye. This also applies to the weakest sources for which a reading accuracy of 10 to 20 seconds of arc is assumed.

Scientists from the USA and the United Kingdom, whose countries are contributing financially to the project, will also carry out observations with ROSAT. The British scientists will launch a small, wide-angle telescope on that mission. It is designed to cover the fringe area between X-radiation and ultraviolet light, an area which has so far been largely neglected by research. The British XUV telescope operates in the 60 to 300 Ångström wavelength range. The Americans, for their part, will contribute an electronic X-ray image converter which they previously used on their Einstein mission for research into X-ray astronomy. It produces extremely sharp black-and-white pictures.

Hermann-Michael Hahn/Eugen Hintsches

Infrared astronomy in space began with the successful mission of the satellite IRAS in 1983. It surveyed the sky from January to November and made a heat-radiation recording in four "colours" for the first infrared stellar map showing almost 300,000 objects. The project which the Americans, British and Dutch had begun jointly, has now been picked up again, and with great promise, by Europe's largest research satellite to date:

Peeping into the Colder Cosmos

The infrared observatory (ISO) which was developed by the European Space Agency, ESA, will, if all goes according to schedule, be taken into an elongated orbit by an ARIANE-4 carrier rocket in 1992. ISO will climb to a maximum height of 39,000 kilometres from where it will carry out observations uninterruptedly for up to 10 hours. Like IRAS, ISO is to be equipped with a telescope featuring a 60-centimetre aperture; its perceptive properties in the invisible heat-radiation area, however, will be a hundred times better. It will be able to detect a large snowball at a distance of 3,000 kilometres.

The instrument is equipped for a wavelength range of between two and 200 micrometres, thus bridging a major part of the infrared "gap" between the areas of visible light and radio radiation.

It will thus be possible to gain many new insights into those parts of the more or less colder cosmos where planetary systems begin to condense in their earliest stages from rings of dust and gas around distant suns.

Observations of this kind have already been made by IRAS in the proximity of the star WEGA: some four dozen phenomena have now revealed that planet systems are not at all uncommon in outer space. Since heat radiation of this kind is also capable of penetrating dust, many of the obscure regions of the universe will have to disclose their secrets. It is even hoped that information can be gained from clouds with a temperature of −250 °C.

These findings would not be possible, however, if it were not for excellent technological means. As early as the 1960s, Professor Hans Elsässer and his colleagues at the Heidelberg Max-Planck-Institut für Astronomie (Max Planck Institute of Astronomy) began to work on this new technology. Their activity has turned this romantic old university on the banks of the Neckar River into a sort of Mecca for infrared astronomy. The development culminated in the erection of a 3.5-metre reflecting telescope, the largest of its kind in the world, on top of the Andalusian mountain of Calar Alto, the German-Spanish centre for astronomy. This telescope has unlimited applications in the infrared area.

Today, the development of heat-radiation detectors has reached the point where outputs of more than 10^{-17} watts can be picked up, i.e. the one-hundredth part of a billionth of a watt. Even in the case of room temperatures, heat-radiation comes to 10^{-8} watts which clearly illustrates the basic problem of these observations. In other words, the infrared astronomers' "telescope" must not be a million or billion times warmer, i.e. "brighter" than the objects the scientists wish to observe. This is why the essential "pitch blackness" can only be achieved by extreme low-temperature technology which represents a no less challenging task than detector development.

As a consequence, the 60-centimetre telescope mounted on the ISO satellite which weighs 1.8 tons and is more than five metres long, and all the basic electronic equipment have to be kept at a temperature of between -260 and -270 °C. According to present plans, this temperature has to be sustained for up to 600 days. For this reason, the research satellite is being fitted out with two ring-shaped tanks, each of which has a capacity of 750 litres. One tank will contain 105 kilo-

Illustration of the ISO, the infrared observatory: this largest European research satellite to date, in which scientists from four Max Planck institutes are involved, will put Europe out front in infrared astronomy.

(Illustration: ESA)

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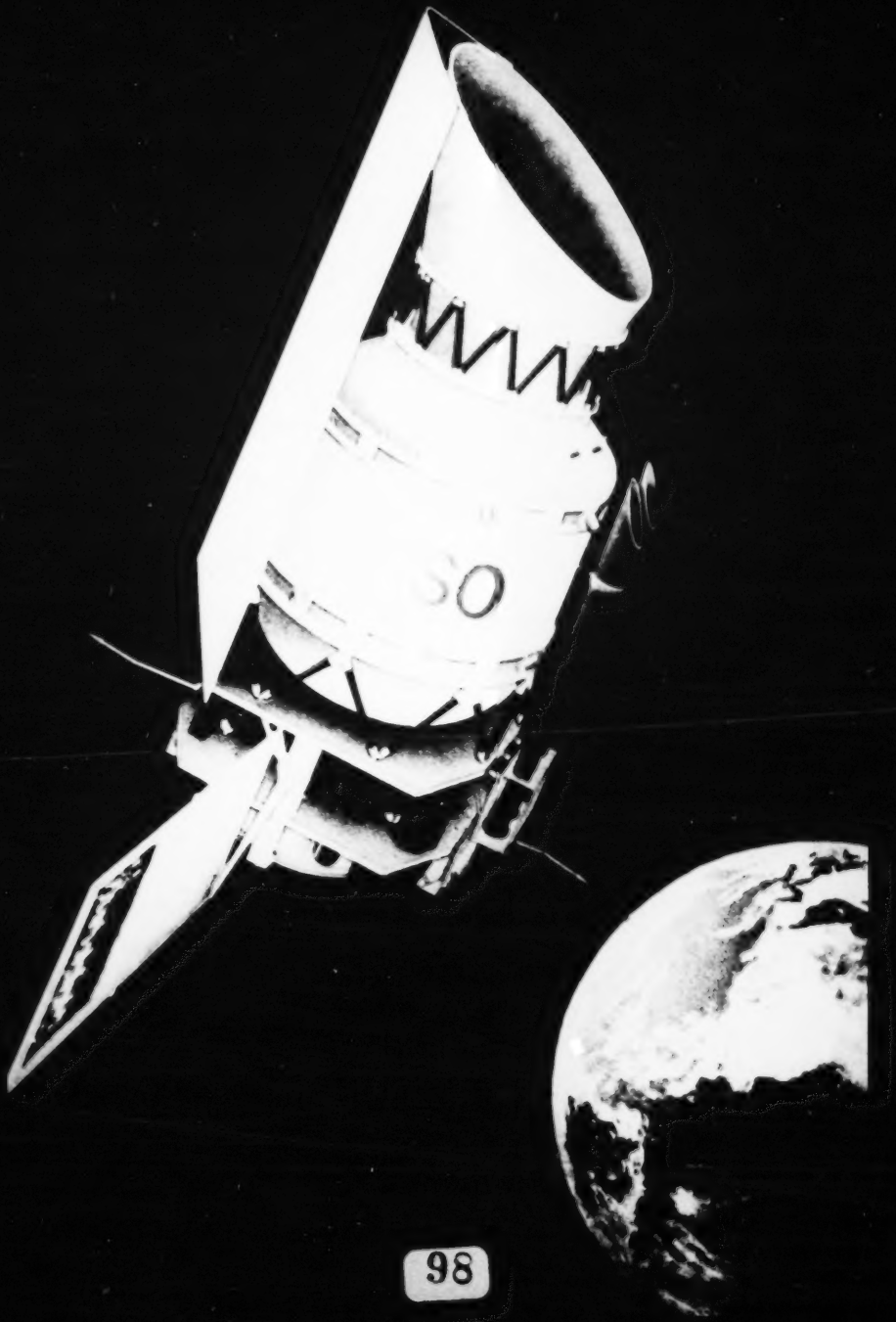

grammes of superliquid helium with a temperature of −270 °C; the other will contain 50 kilogrammes of liquid hydrogen which, at a temperature of −252 °C is not quite that cold. Nevertheless, its cooling properties are some twenty times more effective than those of helium. At the same time, with the way space travel is developing, the experts have now come to realise that the refueling of such satellites is inevitable.

In mid-1985 ESA named the four persons who will be mainly responsible for the development of the instruments for the ISO project, in which four Max Planck scientists are also involved. The four principal investigators are Professor Dietrich Lemke, Max Planck Institute of Astronomy, Heidelberg; Catherine Cesarsky, Institute of Astrophysics at CEN, the French nuclear research centre in Saclay near Paris; Thys de Graauw, Netherlands Space Laboratory, Groningen; and Peter Clegg, Queen Mary College, London.

The German Federal Ministry of Research and Technology, and the Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt, DFVLR (German Aerospace Research Establishment) in Cologne have already pledged financial assistance and cooperation for the German contributions to this ambitious project. There is another aspect which did not quite develop as originally planned, but which will nevertheless enrich this undertaking with a vast wealth of scientific and technological experience. Some years ago, there were plans for a German Infrared Laboratory, GIRL. It was supposed to be used on several occasions as a payload on board a European space laboratory for periods of two weeks at a time. But when the objective computer calculations were put on the table the whole project turned out to be far too expensive because of the transport costs into space.

What has not been "terminated", however, is the experience gained by the German infrared astronomers. Their contributions to the ISO project will enable Europe to cast a scrutinising glance into the colder regions of the universe, thus acquiring a leading position worldwide in this scientific field.

Florian Moritz

The Challenger disaster put an end to all plans to launch Galileo, the Jupiter probe, in May 1986, as originally scheduled. A favourable constellation of the planets must now be awaited before the spacecraft can set off on its 1,200-million-kilometre journey to the largest planet in the solar system. The launching will, in all probability, take place around mid-May 1987. There will also be German equipment on board. German scientists are already racking their brains about a similar mission to Saturn:

Reconnaissance Flights to the Gas Giants

The Galileo probe, weighing some 2,600 kilogrammes, will be taken into orbit by a spacecraft and then start to climb. It will approach the Jupiter system, which has at least 14 satellites (moons), two-and-a-half years later. By that time, the probe will have split up into two largely independent systems. The first half, the probe proper, will head straight for Jupiter and then proceed to parachute down into the planet's atmosphere which is about 1,000 kilometres thick. As it descends, it will transmit measured data for maybe an hour or so before increasing pressure crushes it. The measuring instruments include a device developed by Bonn University and constructed by Messerschmitt-Bölkow-Blohm (MBB), the German space research company. The purpose of this so-called "helium interferometer" is to determine the helium and water content in Jupiter's upper atmosphere.

The second half, Orbiter, likewise fitted with a propulsion unit designed by MBB (Retro Propulsion Module) is to set off on an independent reconnaissance mission which is scheduled to include long-term observation of Jupiter's atmosphere and magnetic sphere. It will also fly by Jupiter's four satellites Europa, Ganymede, Callisto and Io. Io has been discovered to be highly volcanic.

Light was first thrown on Jupiter's secrets when the probe

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Pioneer 10, launched in the spring of 1972, flew over the planet's surface at a height of 135,000 kilometres on December 3, 1973. The great surprise was the fact that the planet's magnetic field proved to be ten times more powerful than that of the earth, and that it extends seven million kilometres into space. Pioneer 11, the sister probe, flew to within 42,000 kilometres of the giant planet on December 2, 1974, following a route over the polar region.

The data supplied by the two probes gave the first indications that Jupiter, with a diameter of about 140,800 kilometres, must be visualized as a sphere consisting mainly of hydrogen, helium and other gases, and that its huge enveloping layer of gas of at least 1,000 kilometres gradually transforms into a liquid state before entering a state of metallic hydrogen deep down at the bottom. It is assumed that the planet's core consists of silicon iron, some 10,000 kilometres in diameter. The entire formation is about 318 times the earth's mass and very hot. It is estimated that the temperature is about 30,000 °C around the centre.

The Great Red Spot, observed for centuries in Jupiter's atmosphere, incidentally is a colder, gigantic eddy zone, probably coloured by phosphorous gas components. The earth would fit into it several times over. It is currently 25,000 kilometres long and some 14,000 kilometres wide. At the turn of the century, however, it was considerably larger.

The two American probes Voyager I and Voyager II reached the planet in 1979 within about four months of one another. It was discovered that Jupiter, like Saturn, has a dust halo, somewhat thinner and "only" 6,500 kilometres wide. Several minisatellites (moons) are located in it. These exploratory flights have produced more information than all former

European and American researchers are jointly planning a further mission to Saturn along the lines of the Galileo mission to Jupiter. This venture not only concerns Saturn and its unique ring system, but also Titan, its satellite, the second-largest of its kind in the solar system. (Illustration: MPG/Schäfer)

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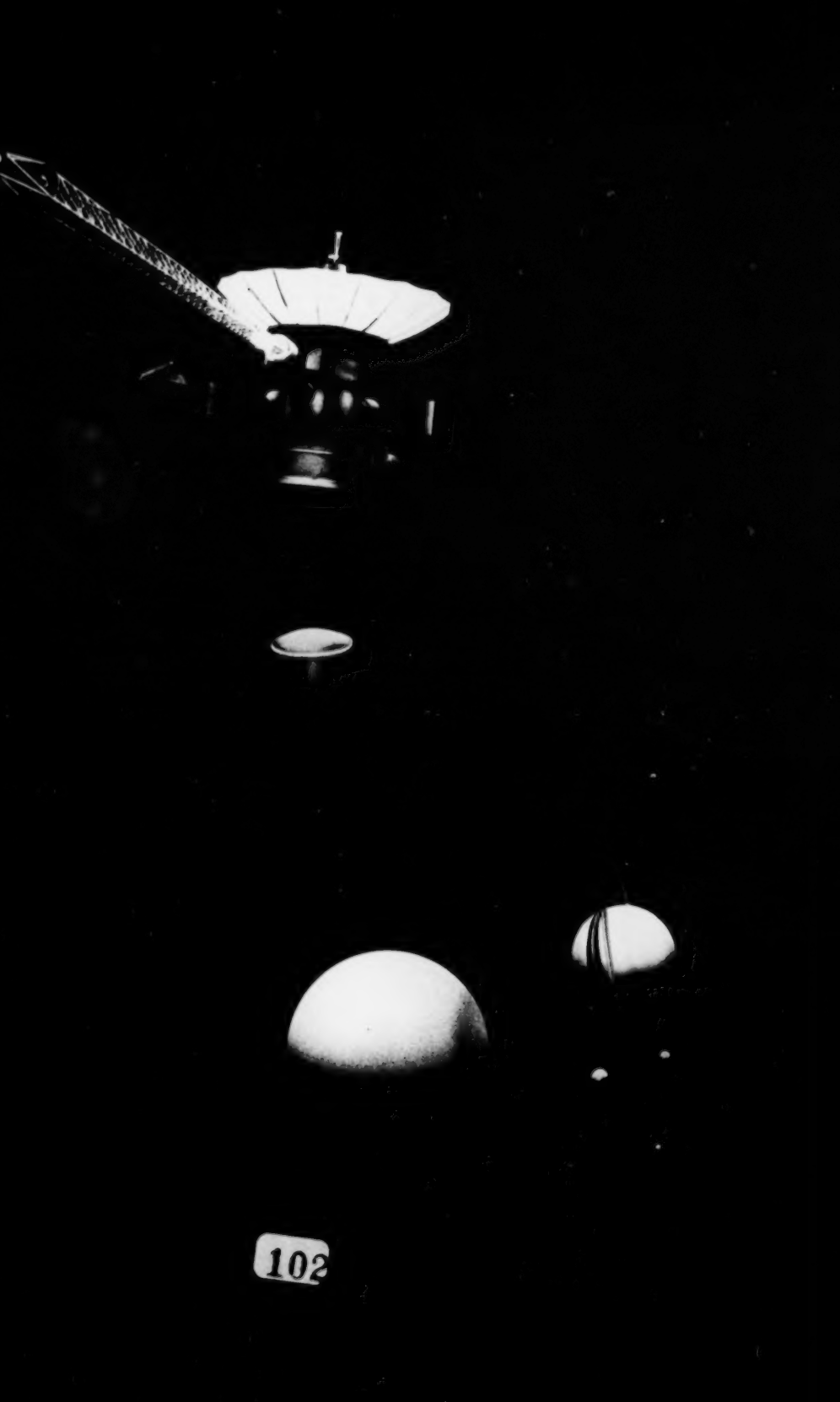

observations made from the earth's surface. It will be interesting to see what Galileo will discover, particularly since Jupiter, like Saturn, according to the latest findings is considered to be a sun of sorts. The only reason it can not ignite is because it is ten times too small. This is why these two gas giants "shine" with only twice the radiation they receive from the sun. Jupiter is a good 800 million kilometres away from the sun (Galileo's trajectory is longer for celestial-mechanical reasons) and Saturn twice as far.

There is a close affinity between these two gas giants in the solar system: Saturn has at least 24 satellites, an equatorial girth of about 120,600 kilometres, and a weight 95 times that of the earth. This affinity has prompted a joint team of experts from the European Science Foundation and the American National Academy of Sciences to work out a mission to Saturn along the lines of the Galileo project. To this end, a symposium was recently held at the Max-Planck-Institut für Kernphysik (Max Planck Institute of Nuclear Physics) in Heidelberg with the goal of outlining this project in greater detail.

This exploratory mission to Saturn and its unique ring system will also include Saturn's satellite Titan which is 5,118 kilometres in diameter. It is larger than the planet Mercury (diameter 4,878 kilometres). Next to Ganymede, one of Jupiter's satellites (diameter 5,287 kilometres), Titan is the second-largest satellite in the solar system. Titan is the only satellite in the solar system featuring an atmosphere, if one disregards the atmospheric traces on Io. Titan's atmosphere is about 10 times as dense as that of the earth. It consists mainly of nitrogen, the inert gas argon, hydrogen-rich molecules such as methane, and other hydrocarbons.

Many researchers also assume that this atmosphere is in a similar state to the state in which the earth's atmosphere was some 3,000 million years ago. There is one big difference, though: it is very cold on Saturn because the planet is so far removed from the sun. Its surface temperature is -180 °C. Since no evidence of oxygen has been obtained so far, it does

not seem very likely that any signs of life will come to light, unless, of course, it is different from what is expected.

According to the European-American team, parts of a Saturn/Titan mission of this nature could be realised not only with the know-how gained from the Galileo project, but also with the remaining spare parts from this mission. This, the experts reckon, would be three times cheaper than designing a completely new spacecraft. Only the special "diving probe" to explore Titan's mysterious atmosphere would have to be specially designed and built. As a result of these deliberations, the Heidelberg experts have estimated that the Saturn mission could start as early as 1992. Eight years later, the Saturn/Titan probe would reach its destination.

Favoured by a planet position which will not occur again until the year 2155, it has proven possible celestial-mechanically to redirect Voyager II onto a "grand tour", which includes Uranus and Neptune but omits Pluto, the planet farthest removed from the sun. Voyager II reached Uranus late in February 1986, reconnoitred it very successfully, and provided the researchers with a highly exciting new finding: this giant planet has a core about the size of the earth and is surrounded by a hot ocean some 8,000 kilometres in depth. The water probably stems from melted comet cores. Three years after flying by Uranus, after a journey of another 1,000 million kilometres away from the sun, the probe will reach the Neptune system and encounter Triton, its satellite, at a distance of about 10,000 kilometres. *Florian Moritz*

On July 2, 1985, ARIANE, the European carrier rocket, was launched successfully at the Kourou European Space Station in French Guiana, South America. It took Giotto, a measuring probe, into orbit. With this mission, the Europeans for the first time became involved in the "hunt" for Halley's Comet, which appears only once every 76 years:

Wild Hunt for Halley's Comet

Halley's Comet, the object of the first interplanetary research mission by ESA (European Space Agency), was probably first described in the year 467 BC. Its "recurrent nature" was first established by British astronomer Edmond Halley (1656–1742). In 1706, he studied the comet observations made in 1531, 1607 and 1682 and concluded that they all referred to one and the same comet. For the first time in the history of astronomy, a theory was formulated which came true: he prophesied that the comet would traverse the sky again in 1758. It has been correctly calculated that the comet takes 76 years to complete its pronounced elliptical orbit. At its greatest distance from the sun, i.e. 5,000 million kilometres, it reaches Pluto's path. At its closest distance, it is some 90 million kilometres from our "central sun".

It is only the sun's proximity that causes the inconspicuous "lumps of dirty ice" to transform into the occasionally splendid comet. The increasing glow of the sun prompts these "cores" to vaporise with ever greater intensity, or to become explosive phenomena. Thus comets bowl along their trajectories, often only roughly calculated, like madly burning sparklers or, as in the case of the comet Biela in 1845, they disintegrate. Because of the incident solar energy, flashing

Giotto, the European measuring probe, encountered Halley's Comet on the night of 13/14 March at a speed of 250,000 kilometres per hour. It passed its core at a distance of no more than 550 kilometres. (Illustration: ESA)

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dust and gases gradually form a "head" up to a million kilometres in diameter around the seemingly tiny core and are compounded in an even more impressively radiant tail, a "shiny nothing", so to speak, spreading out behind for 100, 200 or more kilometres in the opposite direction of the sun.

For a long time it was hoped that what is released from the comet's cores in the sun's proximity could provide information on its composition. But even with the help of spectral analysis it was not possible to conduct a complete investigation of the comet's light. In the course of their investigations the experts discovered that the "ingredients" of the "ice" included ammonia, methane, water, carbon monoxide, carbon dioxide, cyanogen, and other chemical compounds. The "ice" is believed to be "polluted" by considerable quantities of meteoric material.

These questions will most probably be answered by an evaluation (which may take years, in some cases) of the spectacular results of this research project. Several universities and Max Planck Institutes in the Federal Republic of Germany were involved in this project by conducting newly designed experiments. Their work was funded to the tune of DM 35 million by the German Federal Ministry of Research and Technology. The probe itself was named after the famous Italian painter and architect Giotto di Bondone (1266–1337) who, in 1304, incorporated Halley's comet in his Epiphany fresco in the Capella degli Scrovegni all'Arena in Padua, three years after the comet had appeared during Bondone's lifetime.

The probe was temporarily "parked" in a perigeal orbit. Once the supplementary propulsion unit had been ignited, it departed without problem in the summer of 1985 for its rendezvous with Halley's comet. Travelling along a 150-million-kilometre flight path, slightly inclined towards the sun, the probe eventually crossed the comet's trajectory in the night of March 13/14, 1986. The comet itself had already passed the point nearest the sun on February 9, 1986. Moving at a speed of 250,000 kilometres per hour, Giotto penetrated

the comet's head and eventually flew past the core at a distance of 55 kilometres. Just before it had reached that point, the probe began to tumble temporarily, probably after being struck by dust.

The electronic multicolour camera, supplied by the Max-Planck-Institut für Aeronomie (Max Planck Institute of Aeronomy) in Lindau/Harz which had functioned superbly up to this point, was now "blinded" by the unfortunate incident. The other ten experiments were performed without a hitch and provided "phantastic results", to quote Professor Reimann Lüst, the managing director of ESA. In all, Giotto's instruments filled 150 magnetic tapes with data, the evaluation of which will not be completed before late 1987.

The first picture by the Halley multicolour camera, operated during the mission and evaluated by Dr. Horst U. Keller, was taken at a distance of 767,000 kilometres and reached the European Control Centre in Darmstadt at 22.03 hrs (CET) on March 13. The last photograph arrived at 1.03 hrs (CET) on March 14, just 20 seconds before the nearest point to the comet's core was reached at a distance of 1,000 kilometres. In all, some 2,000 photographs were taken: they look like abstract art to the uninitiated. They are in the colours of the 11 spectral areas of light. There are also 69 pictures taken almost simultaneously in three different colours.

The photographs showed that the comet's core, some 15 kilometres long and 10 kilometres wide, is roughly shaped like a peanut. To the experts' surprise, it is twice as big as they had imagined. What was even more astounding was the fact that the core is apparently the darkest piece of matter ever to be discovered in the universe. It is blacker than coal and reflects only a few percent of the sunlight falling upon it. It is probably a crust of organic matter, or even reduced carbon, which girdles the "dirty snow". This is suggested by the fact that water, dust, steam and gases only emerge at certain points which can be seen on this layer. Calculations now reveal that the discharge of such matter, when the comet is at its closest point to the sun, is about 50 tons per second. This means that

the comet may have lost about one percent of its mass during its solar orbit.

The comet's bow shock wave had been located by Giotto's instruments, which tallied with the data provided by the Soviet Venus-Halley probes, at a distance of about one million kilometres. Vega 1 had already encountered Halley at a distance of 10,000 kilometres on March 2, and Vega 2, somewhat closer, on March 9. Three experiments were also carried out by the Max Planck Institute on board these two spacecrafts, while the probes themselves, which constantly transmitted measured data, assumed a sort of pathfinder role for Giotto.

The first dust-particle readings were obtained some 250,000 kilometres away from the comet. Their number steadily increased and "finally" exceeded 120 impacts per second. An analysis of the particle fragments revealed that they consisted mainly of carbon, nitrogen, oxygen and hydrogen as well as a predominant proportion of organic compounds. Their variety was such that the measuring facilities in the 1 to 38 range of units of mass responded throughout.

There is no doubt that these mosaic pieces gleaned from the initial evaluations will soon be assembled into a fascinating picture, which will be enhanced by the data supplied by the two Japanese comet probes Sagigake and Suise. The USA, meanwhile, continues to rely on a former orbiting veteran to measure low-energetic particle radiation. Dr. Dieter Hovestadt, Max-Planck-Institut für extraterrestrische Physik (Max Planck Institute of Extraterrestrial Physics) in Garching, is one of the principal investigators of the American project, namely the ISEE-3 research satellite, launched as far back as 1978 and renamed ICE in the meantime. It was steered around the moon with some breathtaking swing-by manoeuvres and onto a new course where it encountered Halley at a distance of 31 million kilometres on March 28, 1986.

A closer inspection of Giacobini-Zinner, a small comet which completes its orbit once in about every 6.6 years, had also been programmed. This rendezvous took place success-

fully, just as planned. The space vehicle travelled through the inner part of the comet's atmosphere on September 11, 1985; it was the first space probe to carry out such a mission. The journey lasted 20 minutes and covered a distance of 25,000 kilometres, some 7,900 kilometres behind the comet's head.

The assumptions made in 1962 and 1963 by Professor Ludwig Biermann and Dr. Hermann Ulrich Schmidt, Max Planck Institute of Astrophysics, were also confirmed for the first time. Back in those days they had calculated that the dynamics of the comet's waste gases would have to prompt a sort of bow wave or pressure front, as in the case of Halley. And indeed, a pressure front was registered at a distance of some 100,000 kilometres from Giacobini-Zinner. However, it was weaker than expected, which may result from the probe's flight path which was about 7,900 kilometres behind the comet's core and only reached the expanding pressure front afterwards.

The prediction was also confirmed that the lines of electric flux of the interplanetary magnetic field must be like nets around such a comet, thus polarising the comet's own field. What was even more surprising was the fact that the comet made an enormous "noise" in the radio wavelength range. This was attributed to the violent movements by the charged particles in its proximity. Since similar radiowave readings had not been planned for the Halley mission, this discovery was of particular importance.

These diverse observations are both interesting and important, especially since it is assumed that comets stem from the birth of the solar system and are able to throw some light on its genesis. What is particularly fascinating about all this is the question of whether the comets contain complicated organic molecules which could be regarded as a possible preliminary stage to life. *Rolf H. Simen*

Astronomers and solar physicists throughout the world have placed high hopes in a device which was developed under German system-management and has already passed its initial tests with flying colours. It will enable the experts to align their instruments with unprecedented precision with their targets in space while at the same time keeping them absolutely steady:

A "Star Detector" for Space Researchers

No matter how steady a space shuttle is in flight, it is still inadequate for many observation experiments. This is why an alignment system called IPS was developed as early as 1972/73 during the development of Spacelab. It provides observation instruments with a stability in the region of a second of arc – one three-thousand six-hundredth of a degree. This device, designed and constructed by nine European firms under the leadership of Dornier System GmbH, had its début in July 1985. As part of the second Spacelab mission, it carried four experiments into space and fell well short of the prescribed upper limits: the experts were very impressed by its high level of precision.

IPS stands for "Instrument Pointing System". Reduced to simple terms, it consists of a round platform, two metres in diameter. It is mounted on a gymbal system with three drive units which allow it to be turned through three axes. In other words, the platform can be raised and lowered, tilted and turned on its own axis. All the electronic units required for the system are located in the platform.

Furthermore, it has several mechanisms which guarantee a firm link with the payload during the observation mission in space. During the stress phases, i.e. take-off and landing, the payload is uncoupled from the platform to avoid damage, and is firmly bolted to the shuttle or the carrying pallet. This uncoupling is very important since the observation equipment,

moved by the platform, weighs up to seven tons; this would be far too great a load on the ground. Consequently, during ground operations, the payload remains uncoupled; the link is only re-established during weightlessness.

The three identical drive units have axes made of titanium with precision ball bearings in a titanium housing. The drive and control of the axes are provided in each case by two redundant torquers. In conjunction with two insulating and radiating surfaces, a special system controls the heat of the critical component parts. IPS is operated by the Spacelab computer system; its own electronics, including the stabilising sensors, are linked to this large computer via interface. In other words, IPS will be controlled by scientific astronauts from inside the Spacelab via the data display system (DDS). This makes it possible, if the need arises, to modify the observation programmes which are normally defined in detail before take-off.

Once the space shuttle has taken up its observation position, the IPS platform is roughly adjusted with the help of celestial coordinates. The fine tuning is then completed by means of three stellar sensors. Each of these is programmed to track a specific star which it then identifies in relation to the other two stars on the strength of its brightness and position. In other words, a sort of pattern recognition programme takes place: if the sun is to be observed one of the three sensors acts as a "solar sensor".

Once the points of reference have been established and the platform has been adjusted accordingly, the inertial gyroscopes assume responsibility for stabilising the position which continues to be controlled by the sensors. The four gyroscopes, which are interconnected in such a way that they can control all three axes, compensate for all of the shuttle's own movements via servomotors. These movements can be quite considerable; even the astronauts' movements can cause directional changes of several seconds of arc. Changes of that magnitude are too big for IPS which reaches a stability level of half a second of arc during its flight. This is about as much as

the surface of a postcard at a distance of 100 kilometres.

On its first mission, IPS carried four solar research experiments on its platform. Together with its own weight of 1.5 tons, IPS thus weighed three tons. Difficulties were experienced with the fine positioning in the first two days. The sun was repeatedly "lost from sight" in the early stages. The reason for this was the fact that it had not been possible to run realistic ground tests of the equipment intended for use in weightlessness: a simulation programme had to be developed on this basis to write the "flight software" programmes. Later, it turned out that "solar reality" was somewhat different from what had been assumed theoretically. Even so, it proved possible to correct the incorrect parameters. IPS was in operation almost throughout the mission. According to the experts from NASA, "expectations were greatly exceeded".

The development of IPS cost about DM 190 million, half of which came from the German Federal Ministry of Research and Technology. On completion it was handed over to NASA as a Spacelab subsystem; it is now mounted on a Spacelab pallet. Part of the costs resulted from the fact that the structure had to be completely redesigned to make it more rigid and stable in accordance with the experience gained during the first shuttle flights. The experts also realised a new mechanical safety concept. In the event of, say, a defect in the axis drive units, this safety system would make sure that the tremendously large masses would be slowed down or cushioned, thus preventing damage to the shuttle and the equipment.

The second IPS bought by NASA only cost DM 40 million and is currently being prepared for its first mission in space in 1986. Astronomers and solar physicists are now waiting somewhat impatiently for an opportunity to put IPS to further use. In the early 1990s, for example, IPS is to take a giant solar telescope into orbit to investigate magnetic structures. IPS will also assist in survey missions of the earth, even from future space stations. *Dietrich Zimmermann*

5

The Federal Republic of Germany's Space Policy

Generally speaking, the Federal Republic of Germany's space policy is designed to promote basic research, contribute to the development of space technology, and to promote the practical use of the findings in the public and private sectors. It is also aimed at enhancing the space industry's competitiveness, improving international cooperation and, last but not least, helping countries of the Third World to solve their development problems.

Two closely connected focal points in this space programme have been dealt with in detail in this booklet. They are, in the broadest sense, the continuation of extraterrestrial research, particularly the solar system, and medicine and biology under space conditions. But this "outward" look is supplemented by a "downward" one, i.e. science based on surveying the earth from perigeal space. This research is expected to provide new and comprehensive information on the state of the atmosphere, land areas and oceans. Here, inaccessible areas, such as the polar regions, play an important part. Further areas of application include the mapping of unexplored regions, the discovery and exploration of raw-material sources, including water in hot, arid countries, climatological research, environment surveillance, earthquake forecasts, etc. Here, too, a further focal point in the space programme can be mentioned: the realisation of the transition from METEOSAT, the European experimental weather satellite programme, to EUMETSAT, the operational satellite system for European meteorological services.

An important feature of this programme, of course, is the expansion of national and international communications and

general provision of information. One good example of this is TV-Sat, the radio and television satellite which went into orbit and began operations in 1986. Another example is the development of communication and navigation satellites. The object here is to introduce operational systems through the users concerned. This applies in particular to ECS, the European communication satellite system for postal authorities and a telecommunication system which has been especially developed for the German Federal Post Office. The test model, designed by German firms for the planned three DFS satellites, will soon be integrated.

In addition, the special conditions prevailing in open space, particularly weightlessness, offer opportunities to develop new types of materials, as well as related technologies and techniques. These are to form a further focal point in a programme aimed at opening up an explorative, productive phase in space. Here, space itself is an ideal laboratory for investigating materials, processes, biotechnical and biomedical fields. In this connection, a leading role is played by Spacelab, the European space laboratory, developed under German central management as a payload on American spacecraft. Similarly, the space platforms SPAS and EURECA, which were designed in the Federal Republic of Germany, are of major importance.

Acting on a suggestion by the German Federal Minister of Research and Technology Dr. Heinz Riesenhuber, a resolution was approved by the cabinet in Bonn on January 18, 1985, to the effect that this space programme be given new, important objectives. First, within ESA, the European Space Agency, the Federal Republic of Germany will assume system management for the COLUMBUS programme which will make an independent contribution to a manned US space station. Second, the Federal Republic of Germany will cooperate in the ARIANE 5 programme under French system management. The project is aimed at developing a new generation of European carrier rockets, fitted with new power units.

This represents a new state in European space research and

engineering along the path to greater independence. At the same time, these programmes pave the way for transatlantic cooperation in aerospatial transport. The Bonn cabinet decision may be summarized as follows: "The Federal Government regards German space activities as a basic part of its foreign, economic and technological policies. It underscores its intention to secure and develop what has already been achieved on the basis of the Federal Republic of Germany's space programme and transatlantic cooperation".

The development, financing and implementation of the federal government's space programme is the responsibility of the Federal Minister of Research and Technology. There are, of course, numerous cross connections with other programmes at this ministry and other governmental departments. The German Federal Post Office and the Transport Ministry, for instance, are involved in programmes concerned with telecommunications, navigation, surveillance of the maritime environment, and meteorology. These future operational systems will fall under their jurisdiction.

In its role as scientific-technical coordinator, the work performed by the Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt, DFVLR (German Aerospace Research Establishment), is of particular importance. This organisation also represents an intersection for the federal government's related industrial policy. The programme's main point of emphasis is German participation in the joint ESA projects.

Above and beyond this, the programme is coordinated worldwide in collaboration with the Federal Foreign Office and the Federal Ministry of Economic Cooperation. Questions regarding the practical application of newly acquired findings and newly developed technologies often find their way into other government departments. There is close cooperation between the responsible federal ministries and the various federal state governments, particularly with regard to funding DFVLR and the many projects in which the Max Planck Society is involved. There are also numerous points of contact

at the Federal Ministry of Research and Technology with other programmes. This applies primarily to air transport research, data processing, communications technology, electronic modules, environmental research and technology, and climate research. Thus, it is almost impossible to draw a dividing line anywhere since space research has become research for the earth.